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ADVANCED SHUTTLE SIMULATION TURBULENCE TAPS (SSTT)

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16. ABSTRACT

A nonrecursive model (based on von Karman spectra) for atmospheric turbulence along the flight path of the Shuttle Orbiter has been developed which provides for simulation of instantaneous vertical and horizontal gusts at the vehicle center-of-gravity and also for simulation of instantaneous gust gradients. Based on this model, the time series for both gusts and gust gradients have been generated and stored on a series of magnetic tapes which are entitled Shuttle Simultation Turbulence Tapes (SSTT). The time series are designed to represent atmospheric turbulence from ground level to an altitude of 120,000 meters,

The purpose of this document is to provide any potential user of the SSTT with an appropriate description of the characteristics of the simulated turbulence stored on the tapes, as well as instructions regarding their proper use. The characteristic of the turbulence serie , including he spectral shape, cutoff frequencies, and variation of turbulence parameters w th a7titude, are discussed. Information regarding the tapes and their use is presented. Appendices provide results of spectral and statistica analyses of the SSTT and examples of how the SSTT should be used.

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1. INTRODUCTION

The effects of atmospheric turbulence in both horizontal and near-horizontal flight, during the return of the Space Shuttle, are important for determining design, control, and "pilot-in-the-loop" effects. A non-recursive model (based on von Karman spectra) for atmospheric turbulence along the flight path of the Shuttle Orbiter has been developed which provides for simulation of instantaneous vertical and horizontal gusts at the vehicle center-of-gravity, and also for simulation of instantaneous gust gradients. Based on this model the time series for both gusts and gust gradients have been generated and stored on a series of magnetic tapes which are entitled Shuttle Simulation Turbulence Tapes (SSTT). The time series are designed to represent atmospheric turbulence from ground level to an altitude of 120,000 meters.

The purpose of this document is to provide any potential user of the SSTT with an appropriate description of the characteristics of the simulated turbulence stored on the tapes, as well as instructions regarding their proper use. Section 2 contains a discussion of the characteristics of the turbulence series, including the spectral shape, cutoff frequencies, and variation of turbulence parameters with altitude. Information regarding the tapes and their use is presented in Section 3. References cited are included in Section 4. Appendices A and B present the results of spectral and statistical analyses of the SSTT while examples of how the SSTT should be used are provided in Appendix C.

2. CHARACTERISTICS OF SIMULATED TURBULENCE

The non-recursive turbulence model used to generate the SSTT is based on von Karman spectra with finite upper limits corresponding to the dimensions of the Space Shuttle, relative to the scale of turbulence in the atmosphere. Because the scale of turbulence increases with altitude while the dimensions of the Space Shuttle are fixed, the finite upper limits of the von Karman spectra increase with altitude. In order to take into account these spectral changes, for each gust or gust gradient there are actually six time series corresponding to six altitude bands extending from ground level to 120,000 meters, as indicated in Table 2-1. A more detailed description of the characteristics of the turbulence is provided in the subsections which follow.

2.1 TURBULENCE GENERATION PROCEDURE

The six types of SSTT are presented in Table 2-2. For each gust and gust gradient series indicated in the table, the generation procedure involved convolving a discrete white noise signal of unit variance with a discrete approximation of the impulse response function corresponding to the appropriate, dimensionless spectrum [1]. Each of the resulting series consists of 8500 discrete signals. The time interval, T_i, associated with each series was based on the maximum frequency for which the simulation procedure is considered valid. These time intervals and the corresponding limiting frequencies, Ω_{i1max}, are included in Table 2-1 along with the turbulence length scales, L_i.

2.2 DIMENSIONLESS ENERGY CONTENT

The total dimensionless energy content of each time series for each altitude band was established by integrating the corresponding spectra over the appropriate finite limits indicated in Table 2-1. The resulting energy content is presented in Table 2-3. As might be expected the total dimensionless energy content of each of the turbulent gust series is less than or equal to unity. The dimensionless energy* content for each gust gradient, however,

*Actually the term "energy" is not precise when dealing with gust gradients.

TABLE 2-1. SUMMARY OF TURBULENCE PARAMETERS IN DISCRETE ALTITUDE BANDS

BAND #	LOWER LIMIT (m)	UPPER LIMIT (m)	TURBULENCE LENGTH SCALE L_i(m)			TIME INTERVAL T_i (dimensionless)			MAXIMUM FREQUENCY Ω_{i1max}(dimensionless)		
			i = 1	i = 2	i = 3	i = 1	i = 2	i = 3	i = 1	i = 2	i = 3
1	0	30	43.4	27.7	16.8	.6520	1.022	1.684	4.818	3.075	1.866
2	30	304.8	196	190	192	.1444	.1489	.1474	21.76	21.10	21.32
3	304.8	762	300	300	300	.09432	.09432	.09432	33.310	33.310	33.310
4	762	10,000	533	533	533	.05309	.05309	.05309	59.180	59.180	59.180
5	10,000	27,000	20,000	20,000	1,230	.004266	.004266	.06785	736.5	736.5	46.30
6	27,000	120,000	200,000	200,000	11,800	.003511	.003511	.0[illegible]950	894.9	894.9	52.80

NOTE: i = 1 applies to u_1-gust

i = 2 applies to u_2-gust and $\partial u_2/\partial x_i$ gust gradients

i = 3 applies to u_3-gust and $\partial u_3/\partial x_1$ gust gradients

TABLE 2-2. TYPES OF SIMULATED TURBULENCE

Type	Corresponding Spectrum	Comments
u_1	Φ_{11}	longitudinal gust
u_2	Φ_{22}	transverse gust
u_3	Φ_{33}	vertical gust
$\partial u_2/\partial x_1$	$\Phi_{22/11}$	yaw
$\partial u_3/\partial x_1$	$\Phi_{33/11}$	pitch
$\partial u_3/\partial x_2$	$\Phi_{33/22}$	roll

TABLE 2-3. DIMENSIONLESS ENERGY CONTENT FOR GUSTS AND GUST GRADIENTS

ALTITUDE BAND	SPECTRUM					
	Φ_{11}	Φ_{22}	Φ_{33}	$\Phi_{22/11}$	$\Phi_{33/11}$	$\Phi_{33/22}$
1	.6225	.5010	.2752	.5877	.1525	.1557
2	.8595	.8560	.8383	13.147	12.171	12.308
3	.8956	.8952	.8809	24.767	22.643	22.890
4	.9298	.9296	.9197	54.123	49.527	50.060
5	.9977	.9953	.9251	1740.	41.71	95.62
6	1.000	.9973	.9363	2309.	52.08	391.6

is not limited in such a manner and range as high as 391.6. For both gusts and gust gradients the total energy content generally increases with altitude because of similar increases in the limits of integration.

2.3 VALIDATION OF SIMULATED TURBULENCE

A spectra? analysis of each of the aimensionless *time* series has been carried out by means of a Fast Fourier Transform FFT4 [2]. The results, which are presented in Appendix A, demonstrate that the simulated turbulence possesses the proper von Karman spectral characteristics.

All of the dimensionless time series have also been analyzed statistically *to* determine the gust and gust gradient probability density functions. As shown in Appendix B the results of these analyses indicate that both the simulated gusts and gust gradients are normally distributed, with near-zero means and standard deviations consistent with the energy content presented in Table 2-3.

3. USE OF SIMULATED TURBULENCE TAPES

The dimensionless simulated turbulence time series are stored on six magnetic tapes as summarized in Table 3-1. Each tape actually contains six time series corresponding to the six altitude bands described in Section 2. The appropriate procedures for reading the tapes are presented in subsection 3.1, while the proper method for converting the time series from dimensionless to dimensional form is descrioed in subsection 3.2.

TABLE 3-1. INDEX OF SHUTTLE SIMULATED TURBULENCE TAPES (SSTT)

Tape	Time Series	Comments
SSTT-1	u_1 - gust	longitudinal gust
SSTT-2	u_2 - gust	transverse gust
SSTT-3	u_3 - gust	vertical gust
SSTT-4	$\partial u_2/\partial x_1$ - gust gradient	yaw
SSTT-5	$\partial u_3/\partial x_1$ - gust Gradient	pitch
SSTT-6	$\partial u_3/\partial x_2$ - gust gradient	roll

3.1 READING THE TIM SERIES TAPES

The six time series on each tape are stored in parallel in 6-word logical records and are correlated (i.e., at any point in the time series the 6 turbulence values are all generated from the same string of random numbers). Each time series consists of 8500 elements and thus each tape containt 8500 6-word records. Pertinent characteristics of the tapes are summarized in Table 3-2.

The first record on each tape contains a 36-character alphanumeric descriptor. the second record contains the time series identification number (1-6), the number of points in the time series, and the dimensionless generation time step size for each altitude band. The format for this record is

TABLE 3-2. MAGNETIC TAPE CHARACTERISTICS

Host computer:	HP 21-MX Minicomputer
Number of tracks:	9
Header type:	Non-label
Character type:	. bit ASCII
Recording density:	800 bits per inch

"2I10,6(1X,E14.7)". Following these two records the time series is stored in 6-word records as previously described and in the format "6(1X,E14.7)". The order of storage in each record is from lowest to highest altitude band. Thus the first word in each record corresponds to band #1, the second to band #2, etc. Examples of the records as stored on the tapes are presented in Appendix C.

In the actual use of the time series tapes the sampling frequency may be different from the frequency at which the tapes were generated. In fact, the dimensionless sampling frequency will generally be variable. Therefore it will be necessary to interpolate the time series in order to get values at the proper points in dimensional time. Either zero-order or first-order interpolation should be used. Also, as time progresses and altitude changes, it will be necessary to switch altitude bands in the time series consistent with Table 2-1. Because of the manner in which the 6 time series are generated, any discontinuity due to switching time series should be minimal.

3.2 CONYERSION TO DINENSPONAL VALUES

The dimensionless time series on each tape must be converted to dimensional form before actual use in a simulstion exercise. The conversion process generally involves multiplication and/or division by the appropriate turbulence parameters. Examples of the conversion process for both gust and gust gradient time series are included in Appendix C.

For converting dimensionless gusts, u_i, the corresponding standard deviation, σ_i, should be used. Thus

$$u_i^* = \sigma_i u_i \tag{3-1}$$

where

u_i^* - dimensional gust

For dimensionless gust gradient, $\frac{\partial u_i}{\partial x_j}$, the parameters σ_i and L_i are used. Thus

$$\frac{\partial u_i^*}{\partial x_j^*} = \frac{\sigma_i}{L_i} \frac{\partial u_i}{\partial x_j} \tag{3-2}$$

where

$\partial u_i^* / \partial x_j^*$ = dimensional gust gradient

In the case of dimensionless time it is necessary to develop the procedures for converting both from dimensionless to dimensional form, and also to dimensionless from dimensional. In proceeding from dimensionless to dimensional time the dimensionless time step, T_i, represents the basic unit to be converted. The conversion involves the vehicle velocity, V, and the turbulence scale, L_i. Thus

$$\Delta t_i^* = a L_i T_i / V \tag{3-3}$$

where

Δt_i^* = dimensional time step

It is important to note that because both L_i and V vary with altitude, the resulting dimensional tine step Δt_i is not a constant. To obtain dimensional time, t_i^*, a summation process is involved as follows:

$$t_{iN}^* = \sum_{n=1}^{N} \Delta t_{in}^* \tag{3-4}$$

$$= aT^i \sum_1^N L_{in}/V_n$$

where

$$L_{in} = L_i(Z_n)$$
$$V_n = V(Z_n)$$
$$Z_n = \text{altitude at nth step}$$

In converting to dimensionless from dimensional time the basic unit, the dimensional time step, δt^*, will normally be a constant. The corresponding dimensionless time interval, T_{im}, will be

$$T_{im} = \frac{V_m \delta t^*}{a L_{im}} \tag{3-5}$$

The total dimensionless time, t_{iM}, will be

$$t_{iM} = \sum_{m=1}^{M} T_{im}$$
$$= \sum_{m=1}^{M} \frac{V_m \delta t^*}{a L_{im}}$$
$$= \frac{\delta t^*}{a} \sum_{m=1}^{M} V_m / L_{im} \tag{3-6}$$

The dimensionless time, t_{iM}, corresponds to some M' dimensionless time intervals, T_i, plus some fractional interval, T', as follows:

$$t_{iM} = M'T_i + T' \tag{3-7}$$

where

$$0 \leq T' \leq T_i$$

Thus the number of dimensionless time intervals, M', can be computed as

$$M' = \mathrm{Int}(t_{iM}/T_i)$$

$$= \mathrm{Int}\left(\frac{\delta t^*}{aT_i}\sum_{m=1}^{M} V_m/L_{im}\right) \tag{3-8}$$

where

$\mathrm{Int}(\ ) =$ integer value of ( )

The fractional interval, T', can be computed by the relation

$$T' = t_{iM} - M'T_i \tag{3-9}$$

The interpolation process will involve interpolating between $t_{iM'}$ and $t_{iM'+1}$ at the point t_{iM} as shown in Figure 3-1.

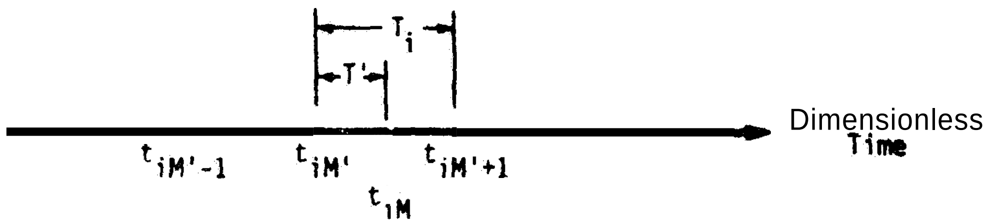

Figure 3-1. Relationship Between t_{iM}, $t_{iM'}$, and $t_{iM'+1}$

In the conversion to or from dimensional values three parameters are required: standard deviation, integral scale of turbulence, and vehicle speed. The variation of the turbulence standard deviation, σ_i, with altftude is presented in Table 3-3. The same table contains the turbulence scale, L_i, as a function of altitude. These tabulated values are consistent with JSC 0700 131.

The vehicle speed, V, fs a function of altitude but also may vary from one trajectory to another. Table 3-4 provides representative values of V as a function of altitude.

TABLE 3-3. VARIATION OF STANDARD DEVIATION AND LENGTH SCALE WITH ALTITUDE*

ALTITUDE (m)	STANDARD DEVIATION OF TURBULENCE			INTEGRAL SCALES OF TURBULENCE		
	σ_1(m/sec)	σ_2(m/sec)	σ_3(m/sec)	L_1(m)	L_2(m)	L_3(m)
10	2.31	1.67	1.15	21	11	5
20	2.58	1.98	1.46	33	19	11
30	2.75	2.20	1.71	43	28	17
40	2.88	2.36	1.89	52	35	23
50	2.98	2.49	2.05	61	42	29
60	3.07	2.61	2.19	68	49	35
70	3.15	2.71	2.32	75	56	41
80	3.22	2.81	2.43	82	63	47
90	3.28	2.89	2.54	89	69	53
100	3.33	2.97	2.64	95	75	59
200	3.72	3.53	3.38	149	134	123
304.8	3.95/4.37	3.95/4.37	3.95/4.39	196/300	190/300	192/300
400	4.39	4.39	4.39	300	300	300
500	4.39	4.39	4.39	300	300	300
600	4.39	4.39	4.39	300	300	300
700	4.39	4.39	4.39	300	300	300
762	4.39/5.70	4.39/5.70	4.39/5.70	300/533	300/533	3001533
800	5.70	5.70	5.70	533	533	533
900	5.70	5.70	5.70	533	533	533
1524	5.70/5.79	5.70/5.79	5.7015.79	533	533	533
2000	5.79	5.79	5.79	533	533	533
3048	5.79/5.52	5.79/5.52	5.79/5.52	533	533	533
4000	5.52	5.52	5.52	533	533	533
5000	5.52	5.52	5.52	533	533	533
6096	5.52/5.27	5.52/5.27	5.52/5.27	533	533	533
7000	5.27	5.27	5.27	533	533	533
8000	5.27	5.27	5.27	533	533	533
9144	5.27/4.22	5.27/4.22	5.27/4.22	533	533	533
10000	4.22	4.22	4.22	533	533	537
20000	6.01	6.01	4.22	6691	6691	955

*Double entries for a tabulated altitude indicate a step change in standard deviation or integral scale at that altitude.

TABLE 3-3. VARIATION OF STANDARD DEVIATION AND LENGTH SCALE WITH ALTITUDE (Continued)

ALTITUDE (m)	STANDARD DEVIATION OF TURBULENCE			INTEGRAL SCALES OF TURBULENCE		
	σ_1(m/sec)	σ_2(m/sec)	σ_3(m/sec)	L_1(m)	L_2(m)	L_3(m)
27000	7.00	7.00	4.22	20000	20000	1230
30000	8.23	8.23	4.66	23533	23533	1443
40000	12.82	12.82	6.03	36693	36693	2231
50000	18.08	15.08	7.51	51786	51786	3128
60000	23.94	23.94	8.90	68623	68623	4124
70000	30.36	30.36	10.28	87063	87063	5208
80000	37.29	37.29	11.65	106998	106998	6376
30000	44.70	44.70	13.01	128338	128338	7622
100000	52.58	52.58	14.35	151010	151010	8941
110000	60.89	60.89	15.69	174950	174950	10330
120000	69.62	69.62	17.02	200000	200000	11800

TABLE 3-4. VARIATION OF SHUTTLE SPEED WITH ALTITUDF [6]

ALTITUDE (m)	V (m/sec)
100	152
300	156
500	158
2000	170
4000	188
6000	200
8000	240
10000	300
20000	500
40000	1928
60000	4695
80000	7468
100000	7521
120000	7510

APPENDIX A

SPECTRAL ANALYSIS OF SIMULATED TURBULENCE

By means of a Fast Fourier Transform [2] spectral analyses of all simulated turbulence have been performed*. The results are presented in dimensionless form in Figures A-1 through A-36. Table A-1 provides a summary of these figures. Also included in each figure is the theoretical von Karman spectra. The agreement between the theoretical spectra and the computed spectra is quite satisfactory.

TABLE A-1. MATRIX OF SPECTRAL ANALYSIS FIGURES

SERIES TYPE	ALTITUDE BAND 1	2	3	4	5	6
u_1	A-1	A-2	A-3	A-4	A-5	A-6
u_2	A-7	A-8	A-9	A-10	A-11	A-12
u_3	A-13	A-14	A-15	A-16	A-17	A-18
$\partial u_2/\partial x_1$	A-19	A-20	A-21	A-22	A-23	A-24
$\partial u_3/\partial x_1$	A-25	A-26	A-27	A-28	A-29	A-30
$\partial u_3/\partial x_2$	A-31	A-32	A-33	A-34	A-35	A-36

*The spectral analysis involved the first 4096 terms of each time series except for bands 5 and 6 for the u_1 and u_2 gusts. For these cases 8192 terms were used.

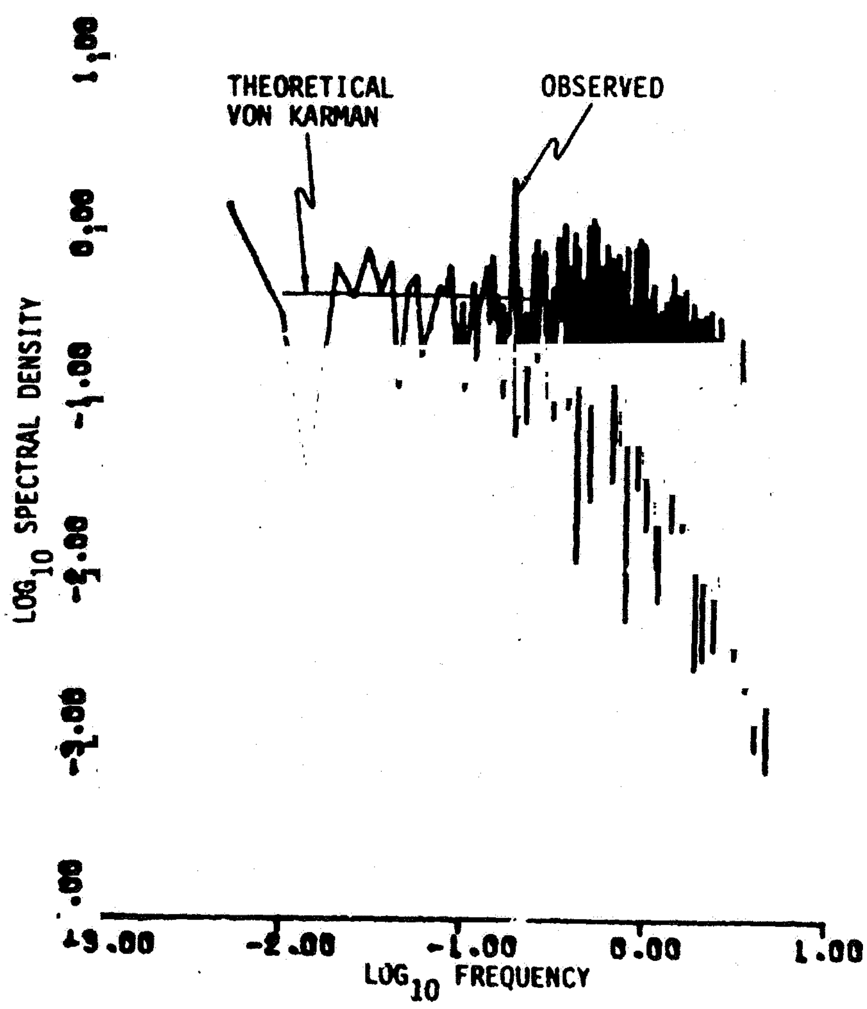

Figure A-1. ω_1 - Gust Spectrum, Altitude Band #1

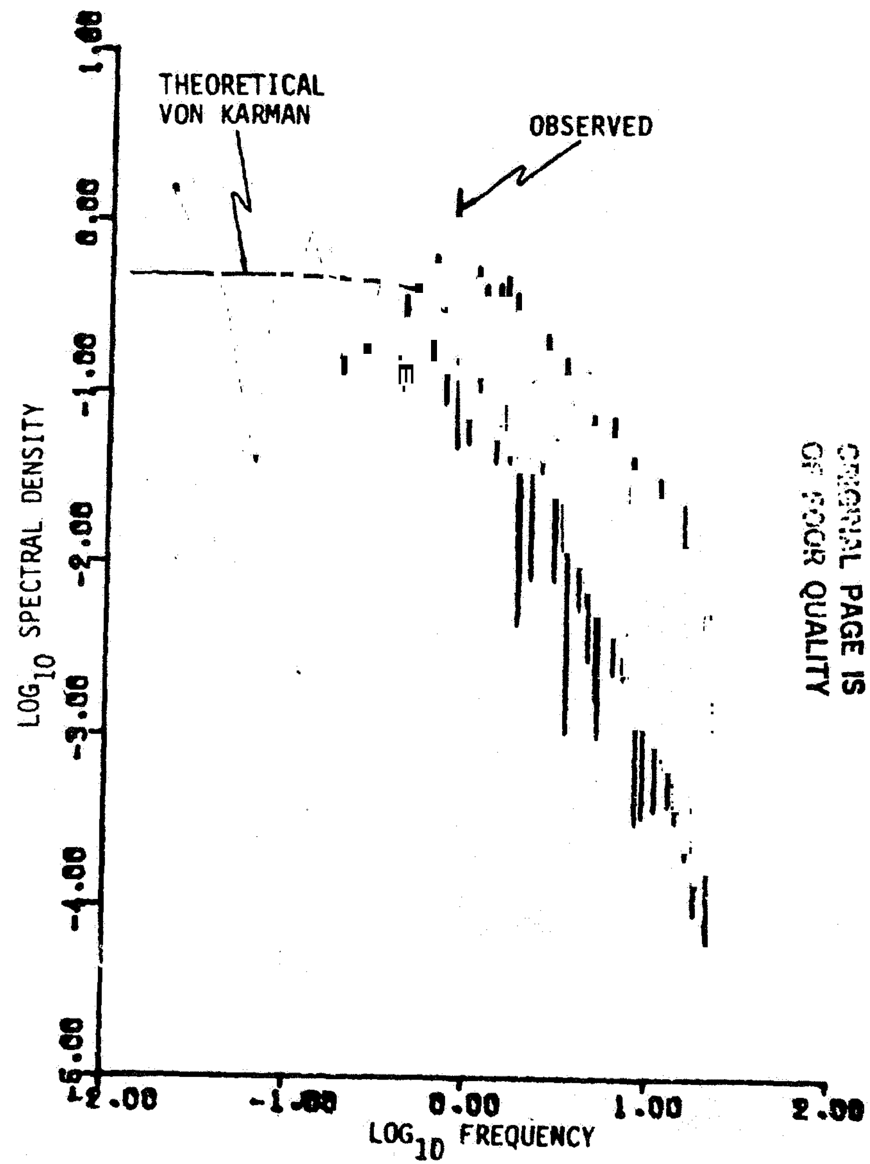

Figure A-2. u_1 - Gust Spectrum, Altitude Band #2

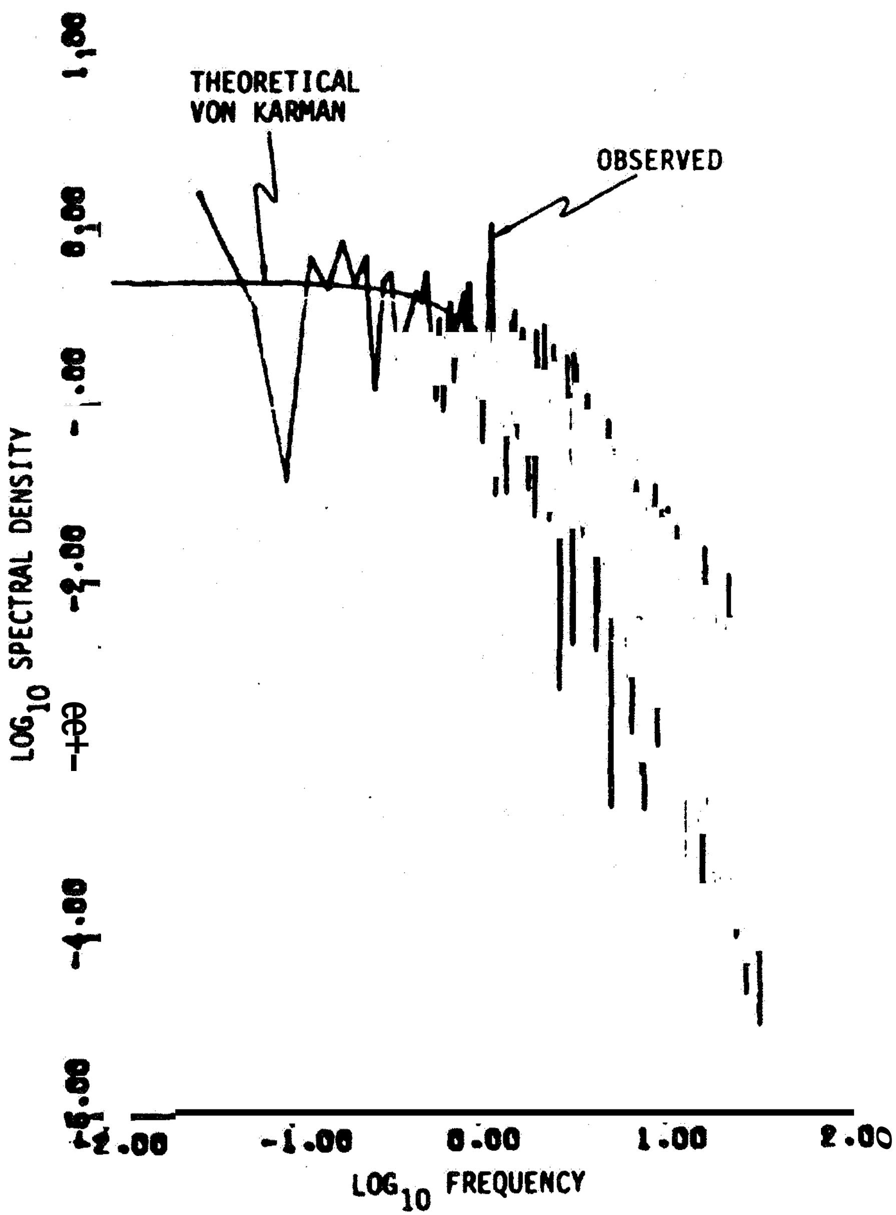

Figure A-3. u_1 - Gust Spectrum, Altitude Band #3

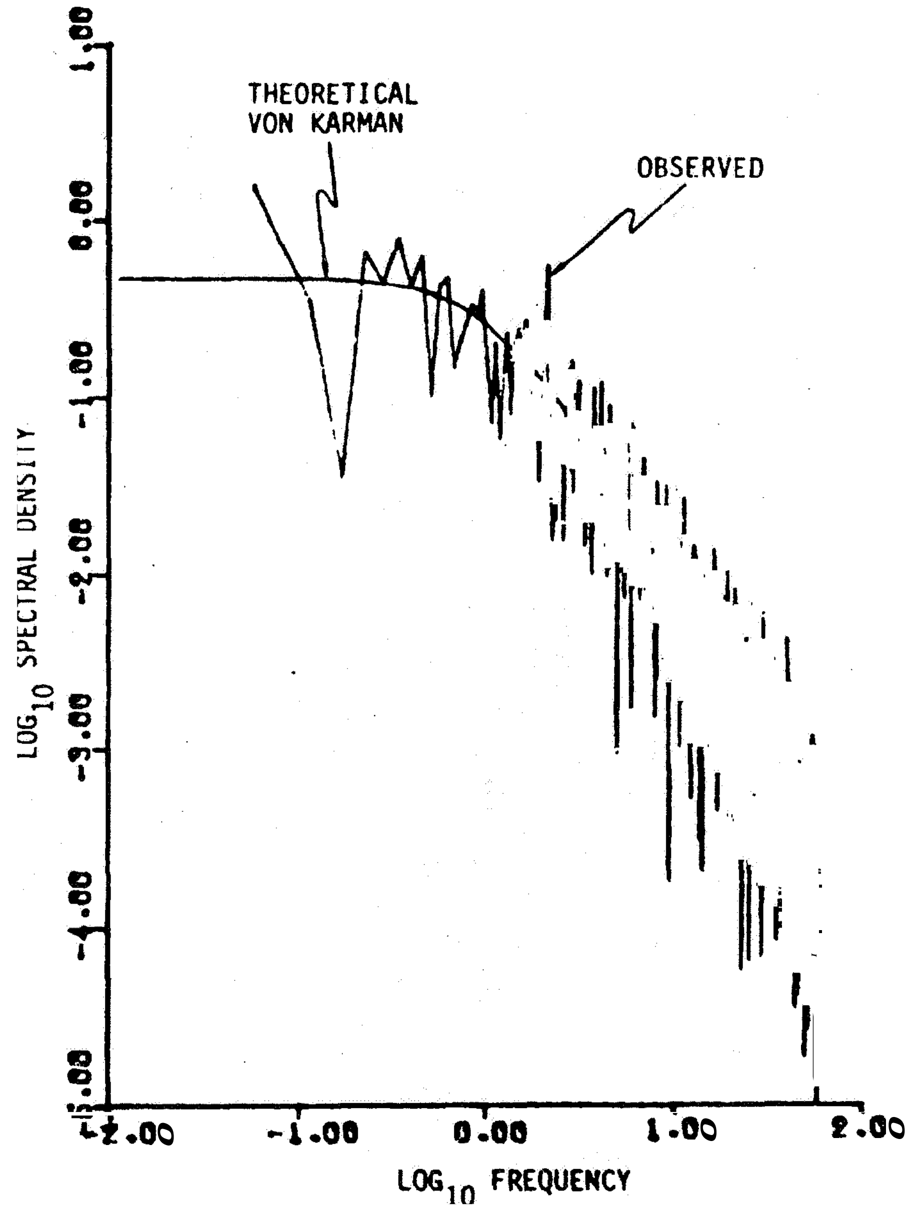

Figure A-4. u_1 - Gust Spectrum, Altitude Band #4

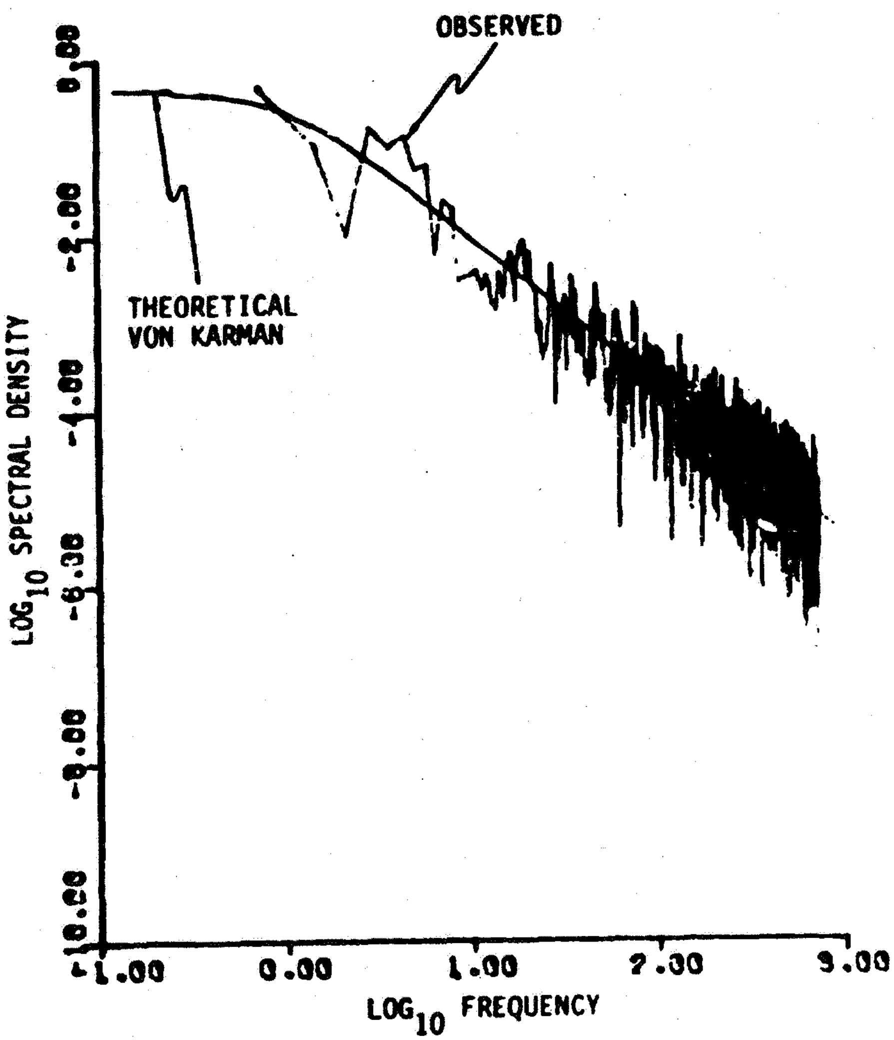

Figure A-5. u_1 - Gust Spectrum, Altitude Band #5

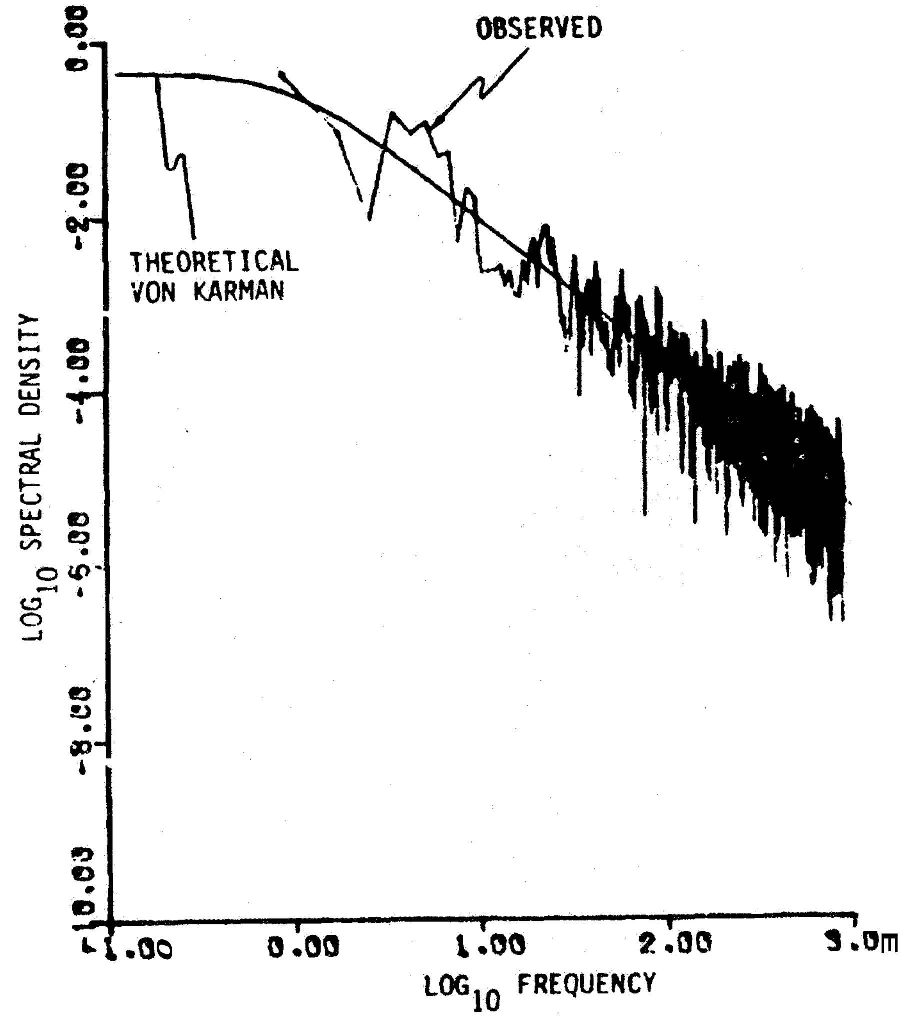

Figure A-6. u_1 - Gust Spectrum, Altitude Band #6

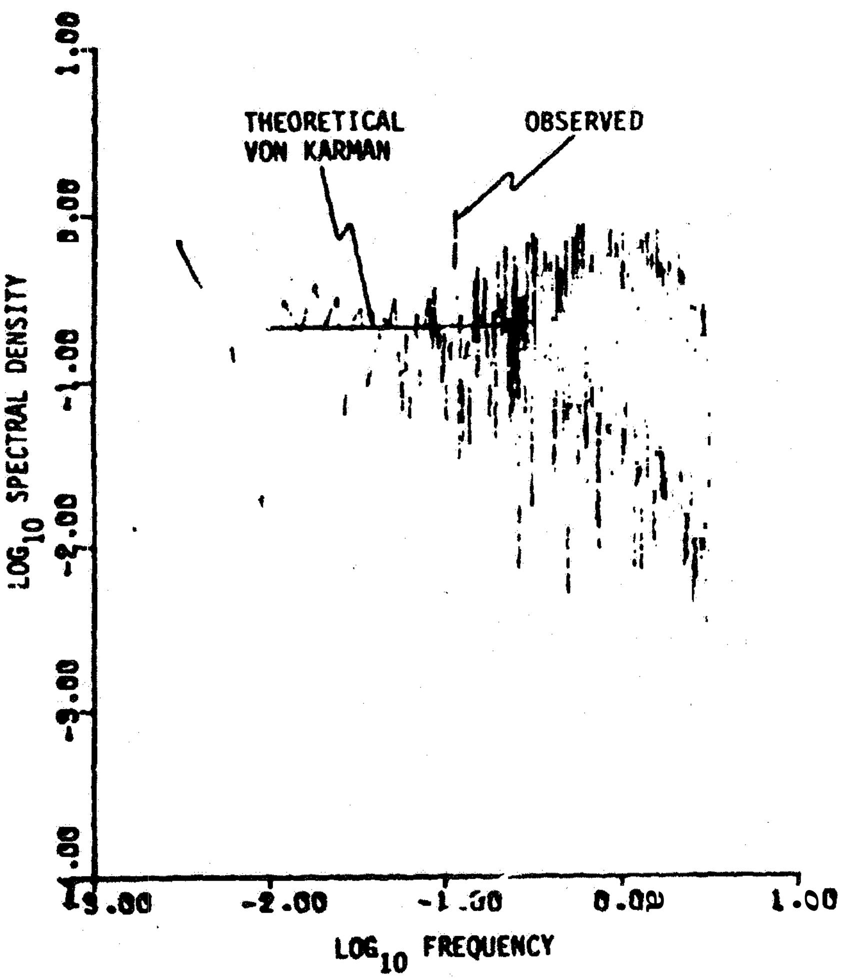

Figure A-7. u_2 - Gust Spectrum, Altitude Band #1

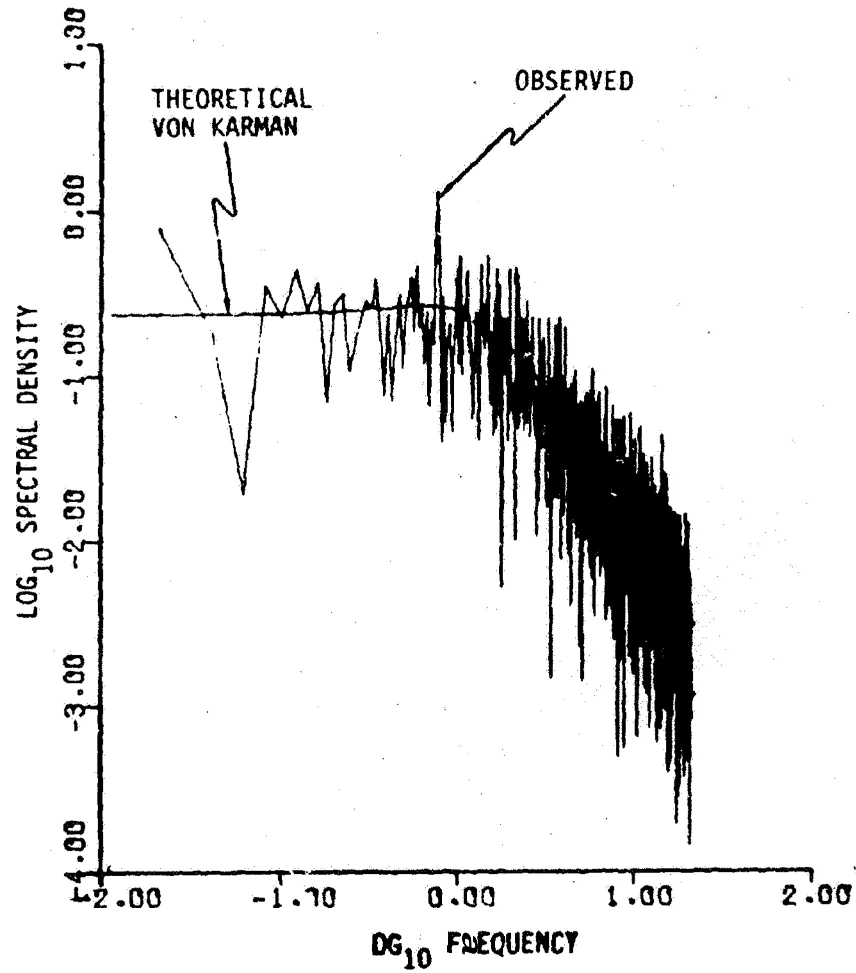

Figure A-8 u_2 - Gust Spectrum, Altitude Band #2

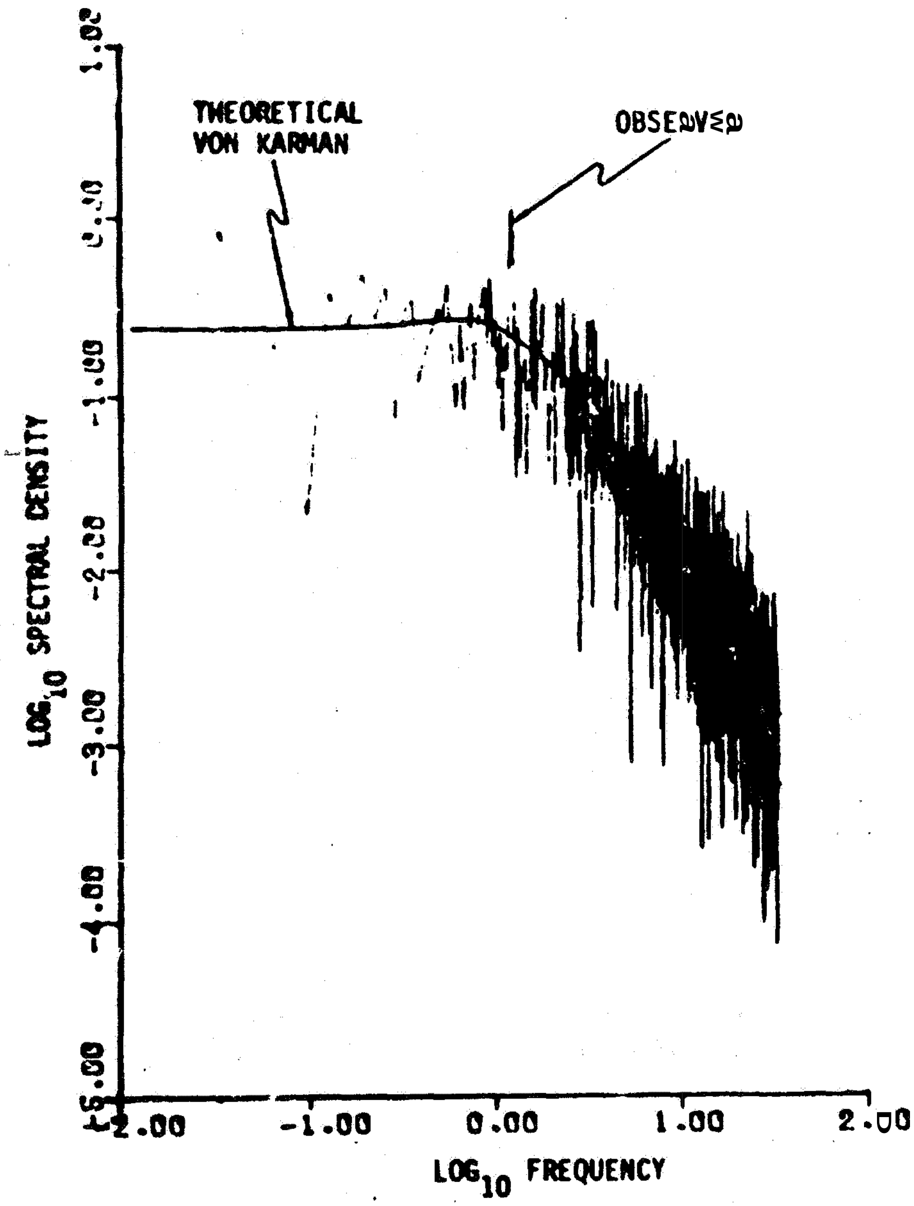

Figure A-9. u_2 - Gust Spectrum, Altitude Band #3

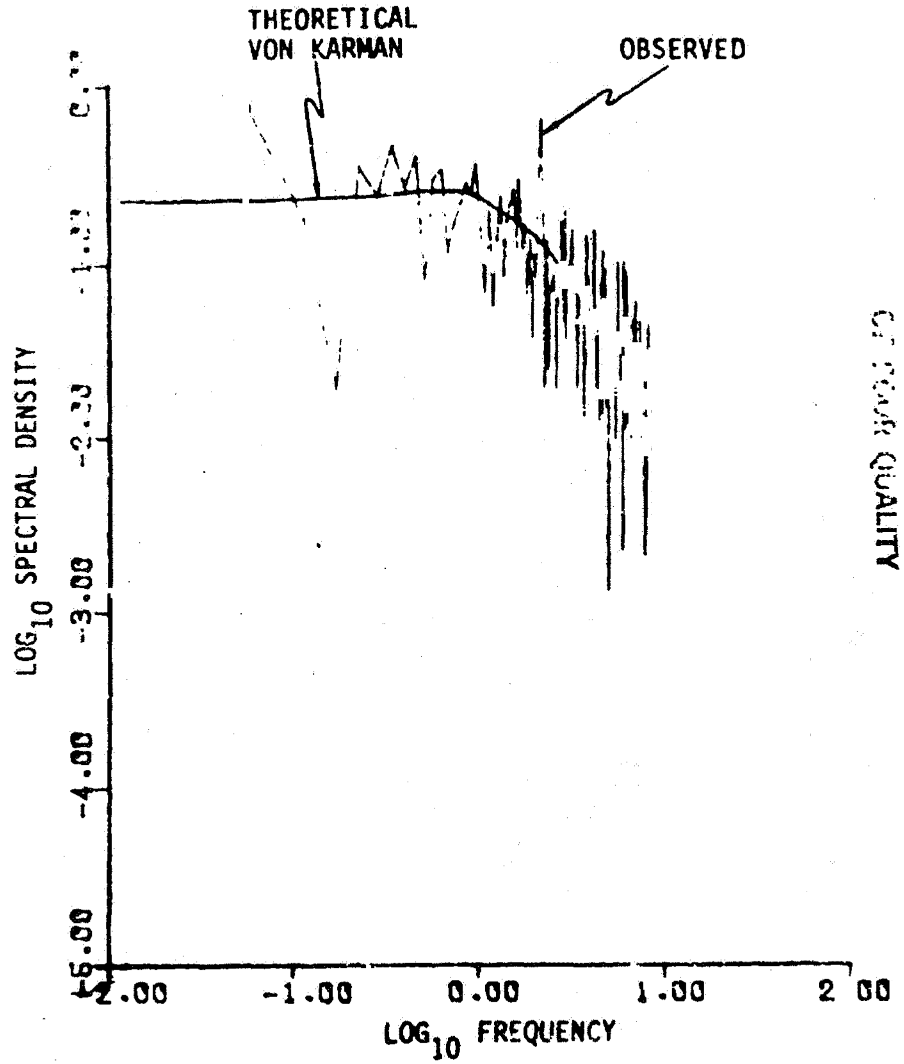

Figure A-10. u_2 - Gust Spectrum, Altitude Ban< #4

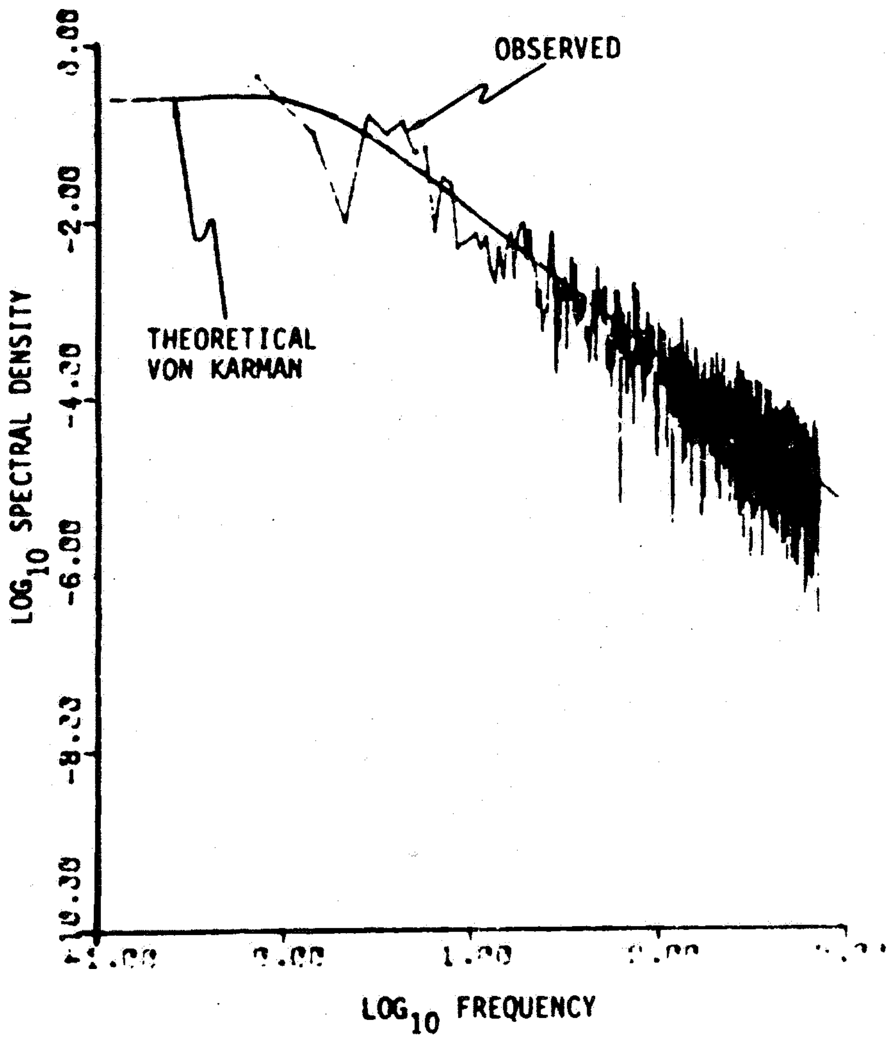

Figure A-11. a_z - Gust Spectrum, Altitude Band #5

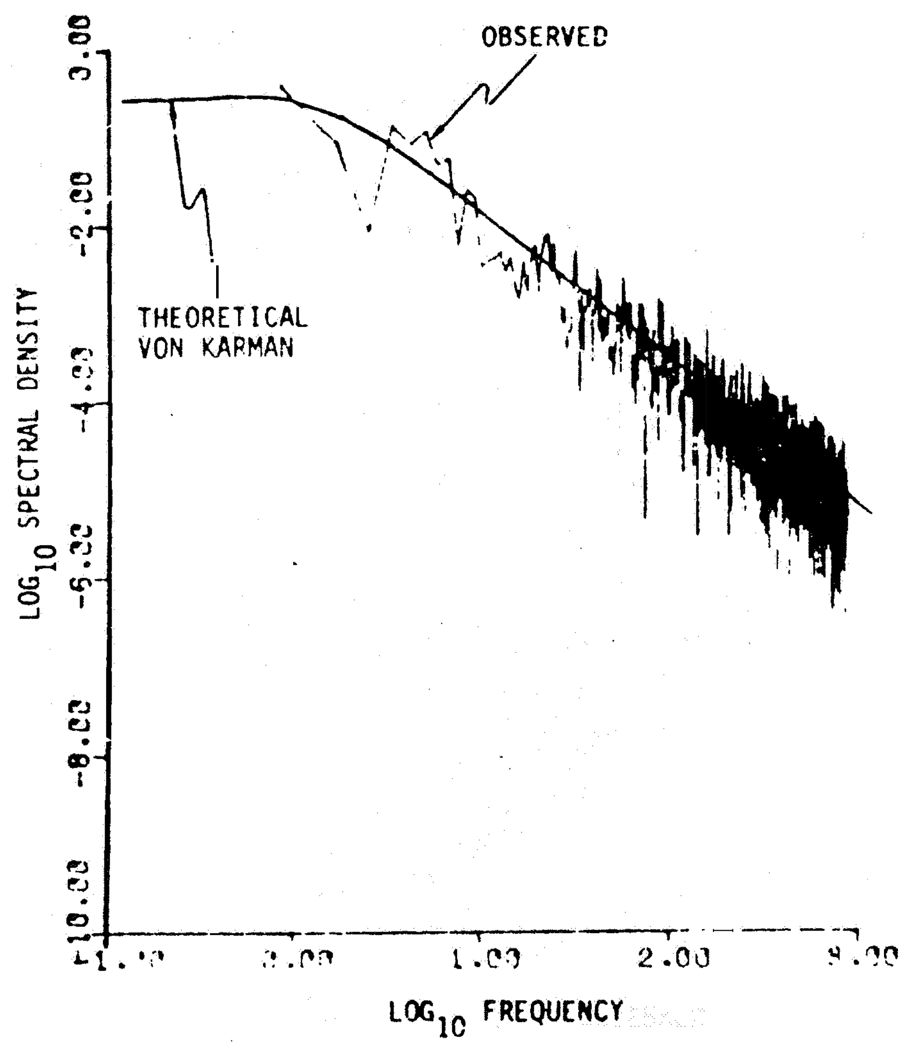

Figure A-12. u_2 - Gust Spectrum, Altitude Band #6

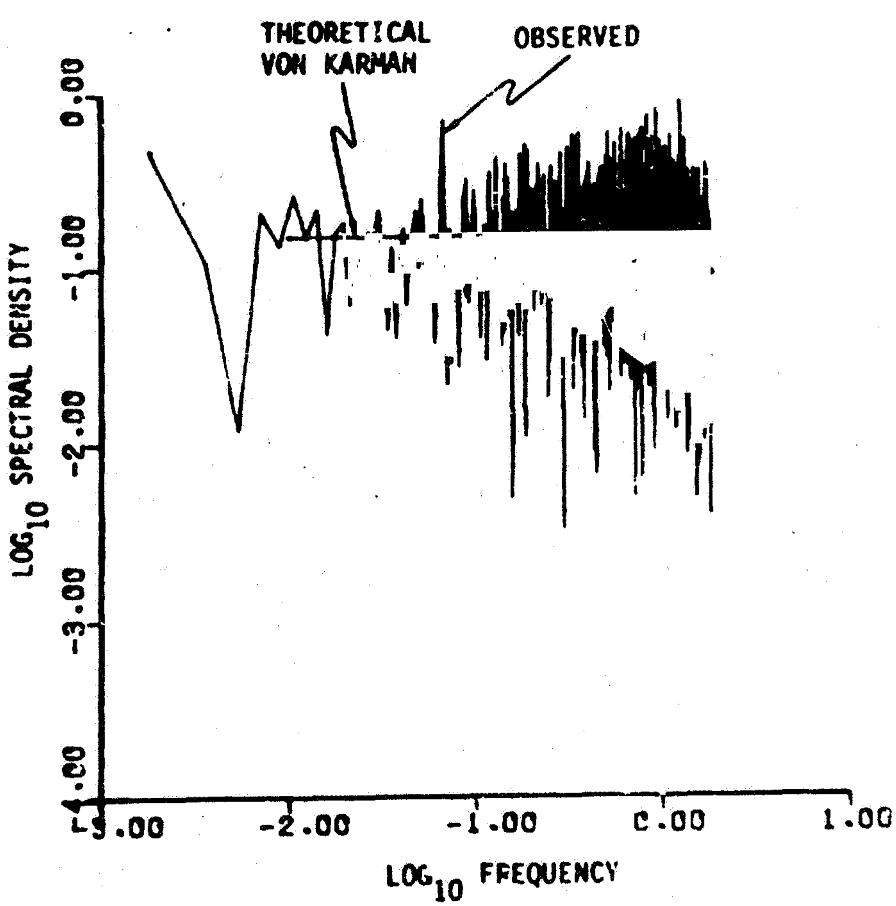

Figure A-13. u_3 - Gust Spectrum, Altitude Band #1

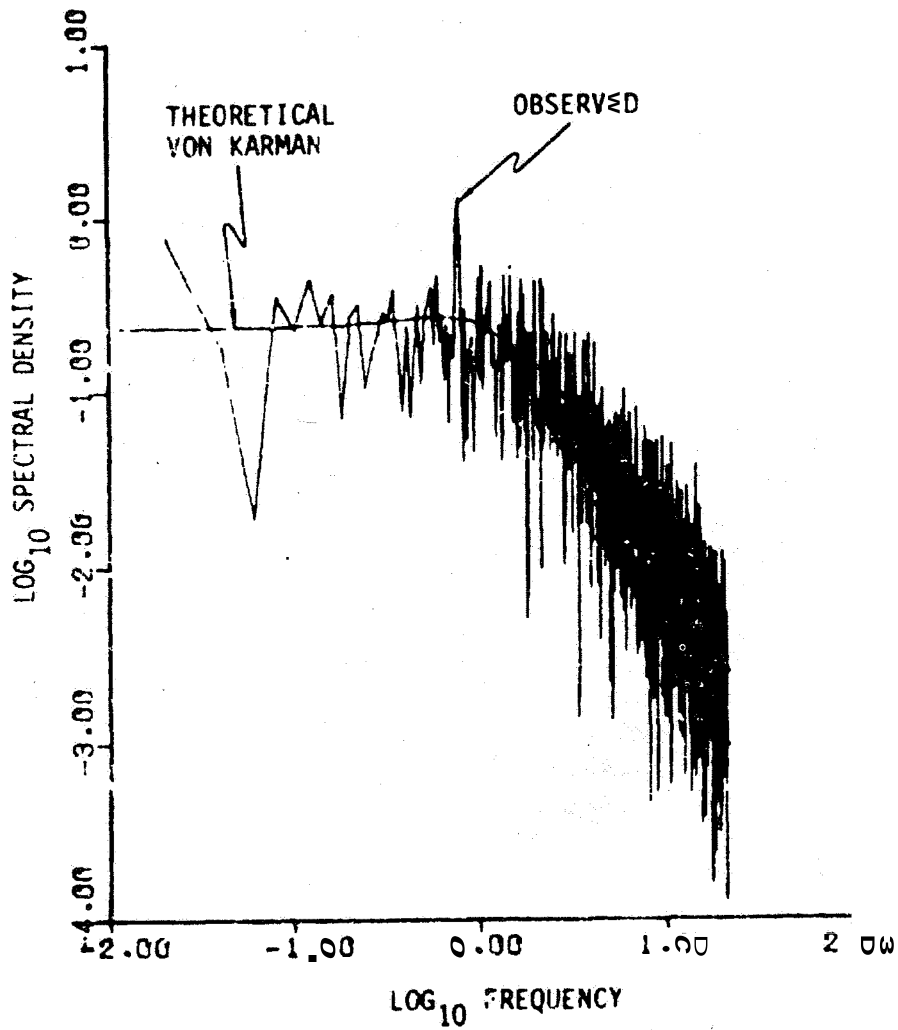

Figure A-14. w_3 - Gust Spectrum, Altitude Bamd #2

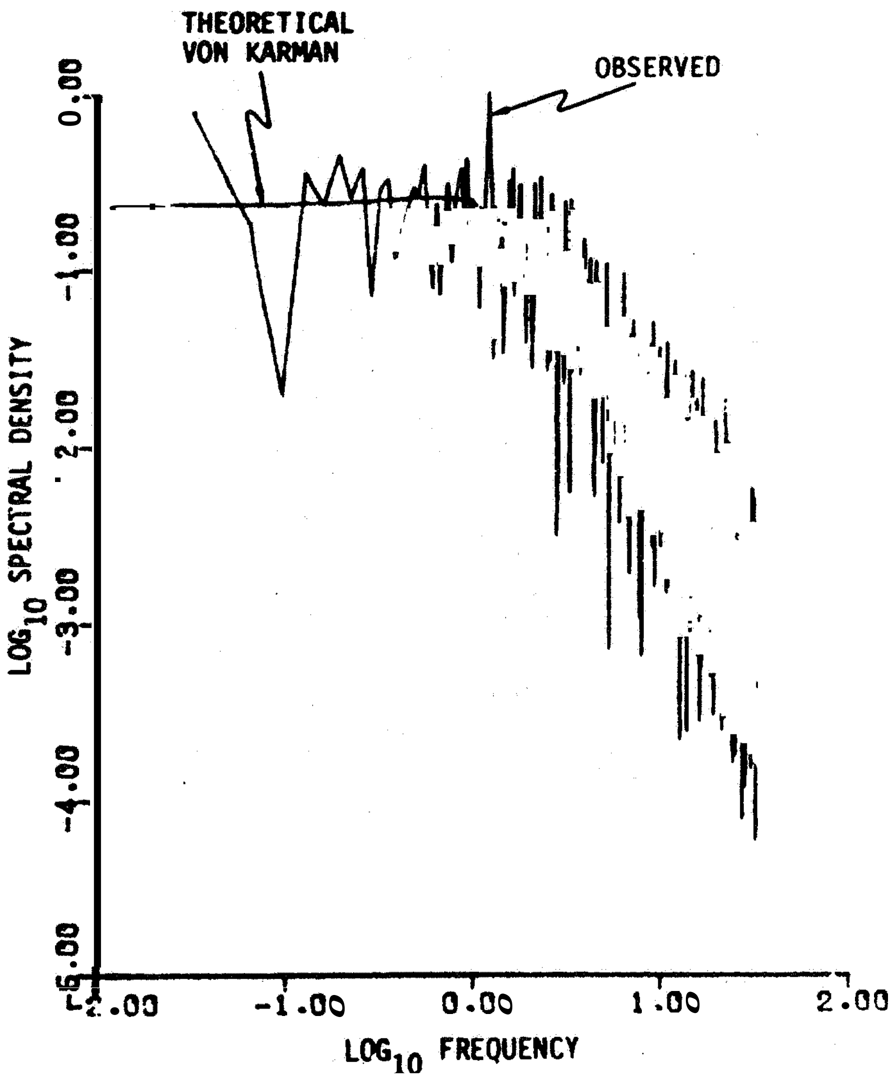

Figure A-15. u_3 - Gust Spectrum, Altitude Band #3

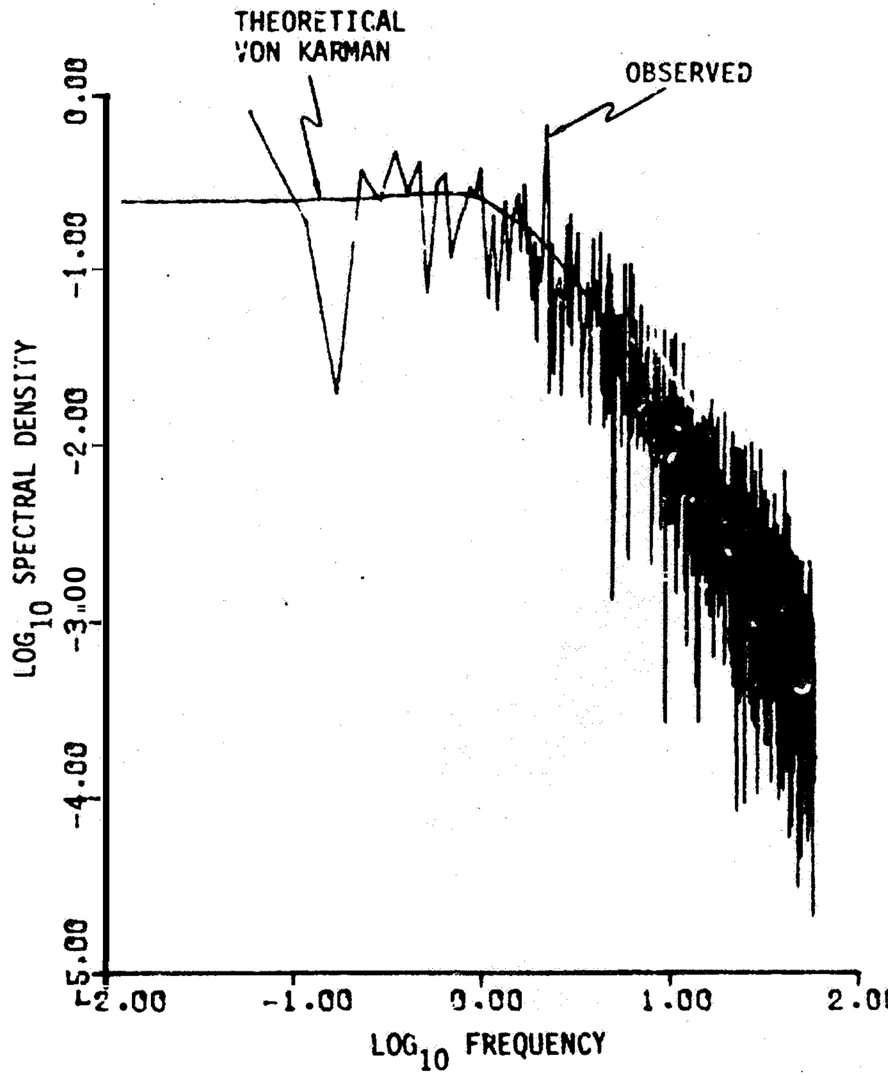

Figure A-16. u_3 - Gust Spectrum, Altitude Band #4

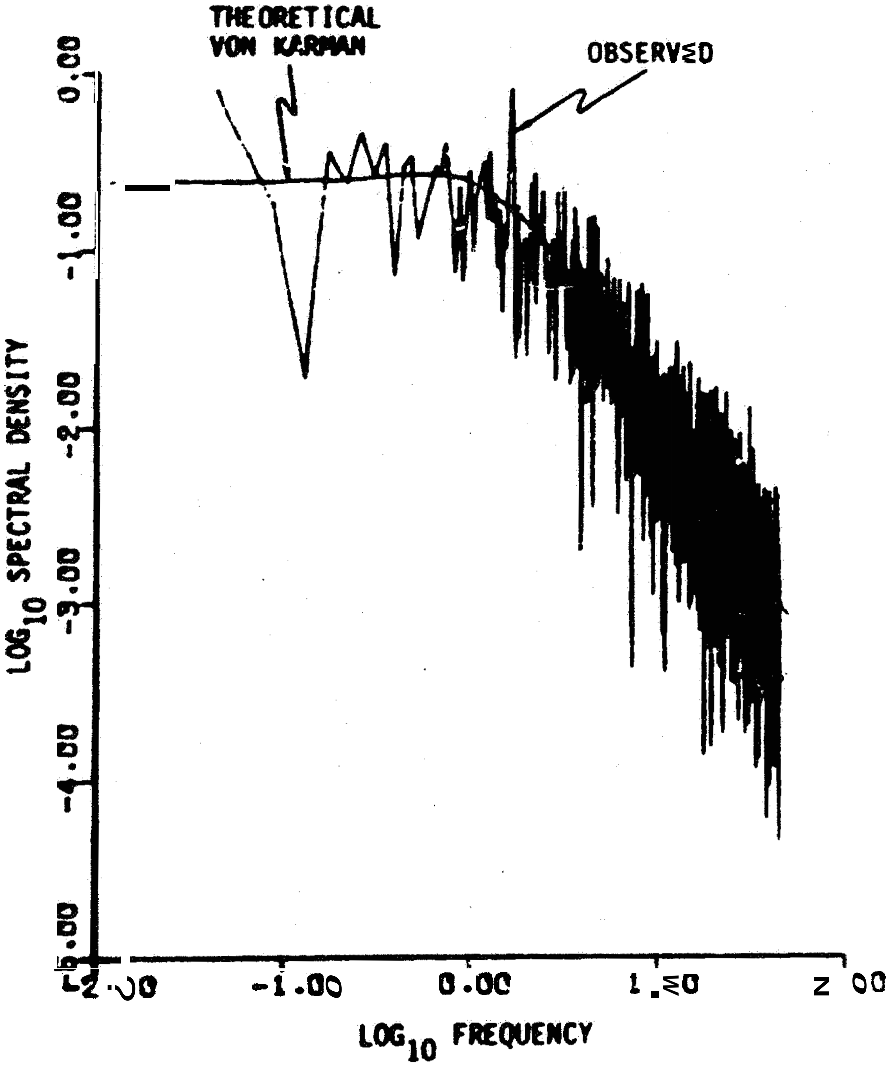

Figure A-17. u_3 - Gust Spectrum, Altitude Band #5

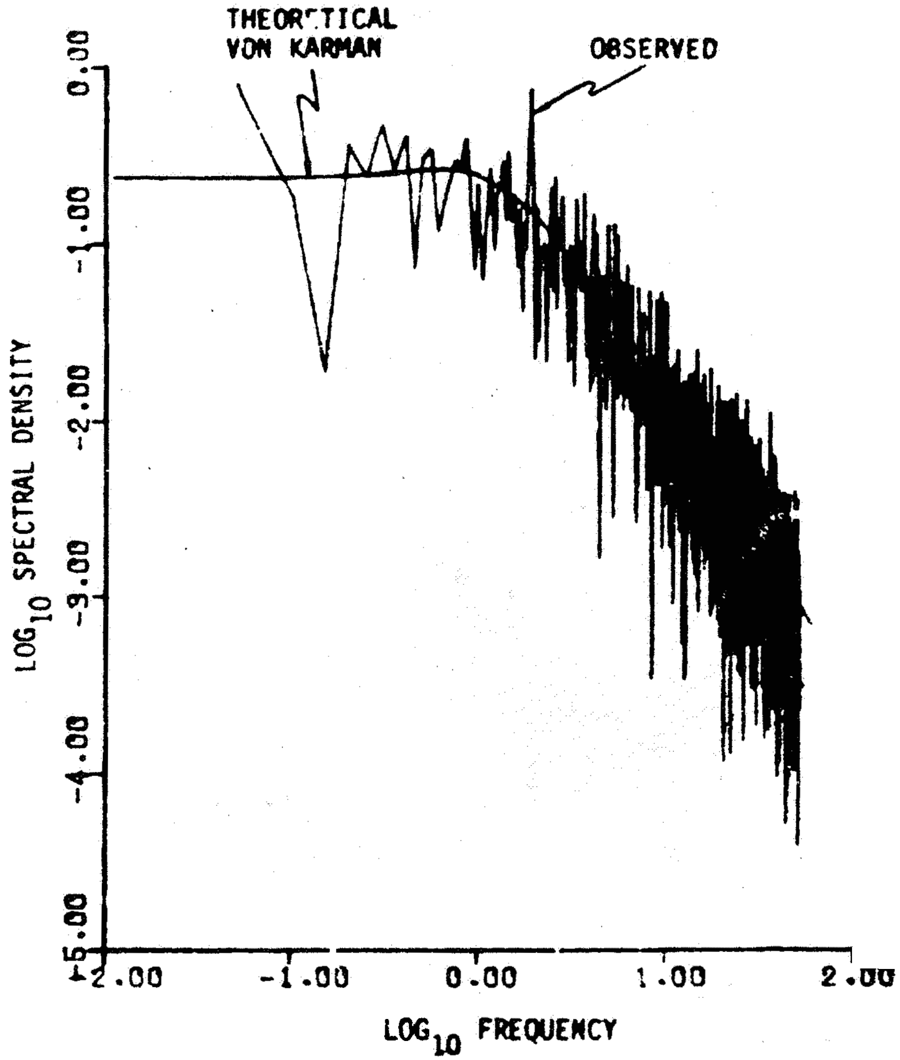

Figure A-18. u_3 - Gust Spectrum, Altitude Band #6

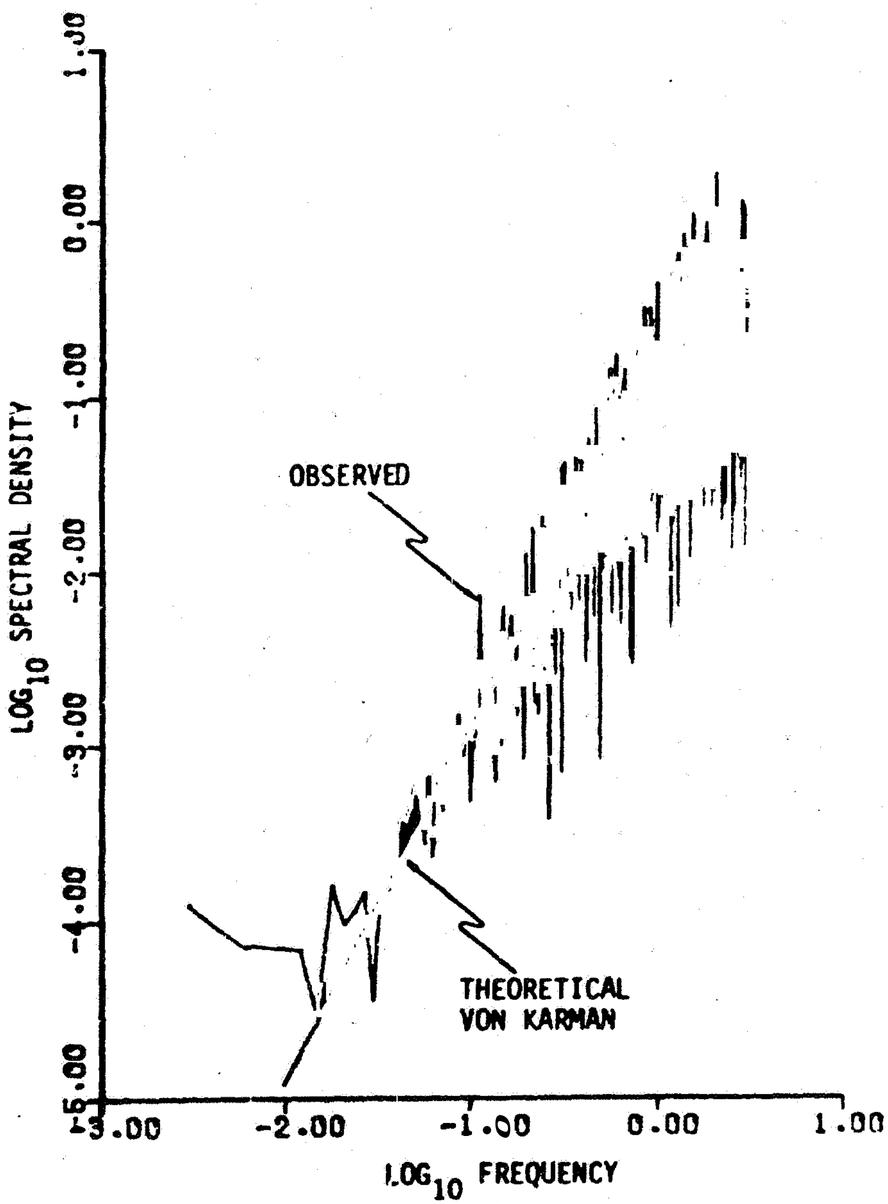

Figure A-19. $\partial u_2/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #1

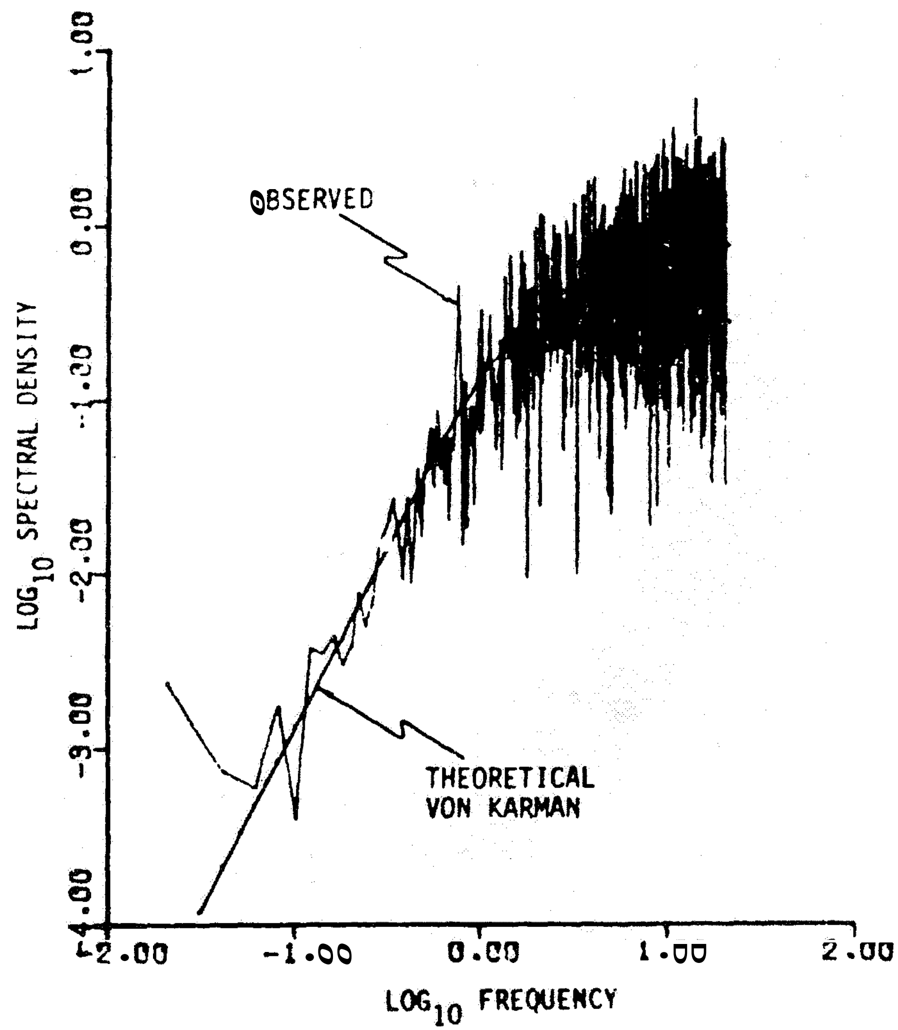

Figure A-20. $\partial u_2/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #2

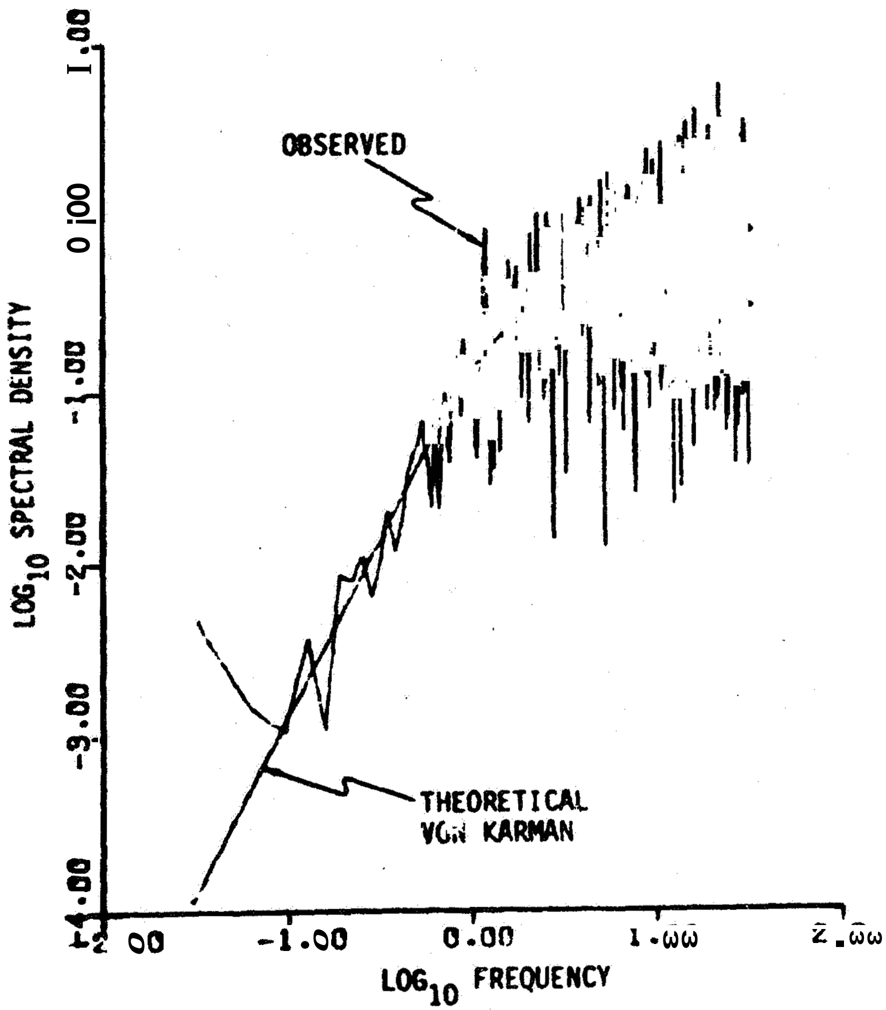

Figure A-21. $\partial u_2/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #3

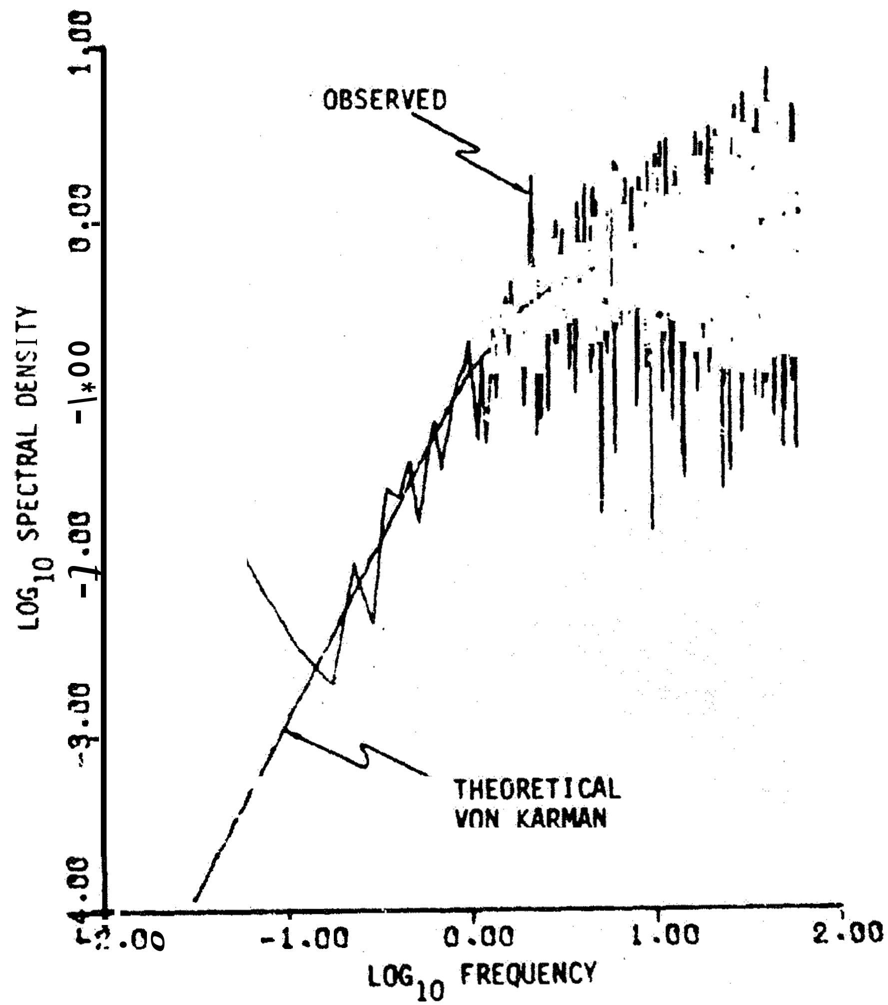

Figure A-22. $\partial u_2/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #4

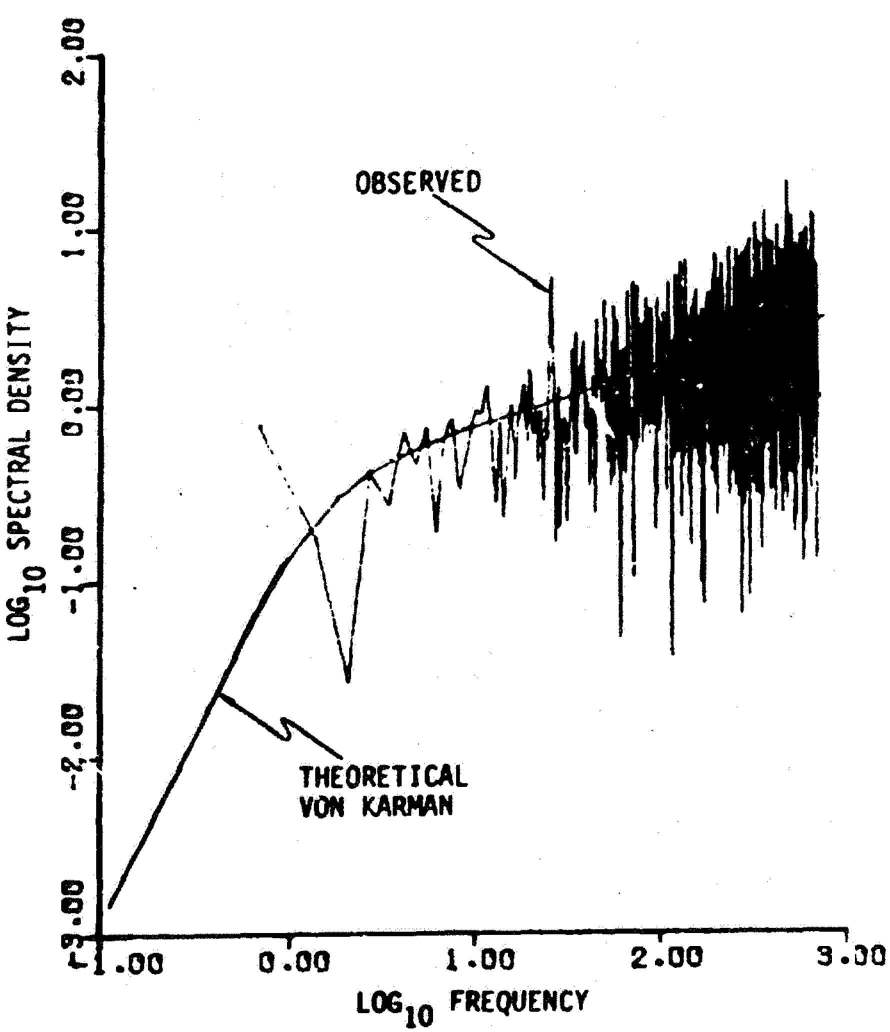

Figure A-23. $\partial u_2/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #5

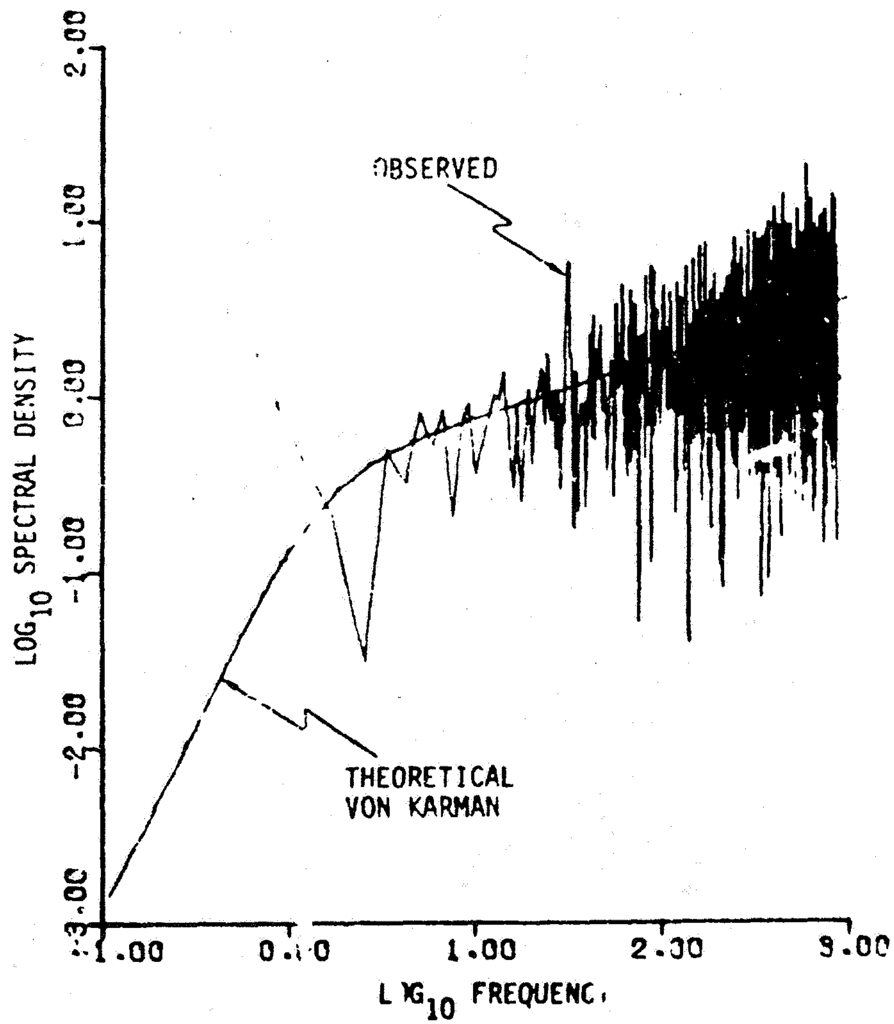

Figure A-24. $\partial u_2/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #6

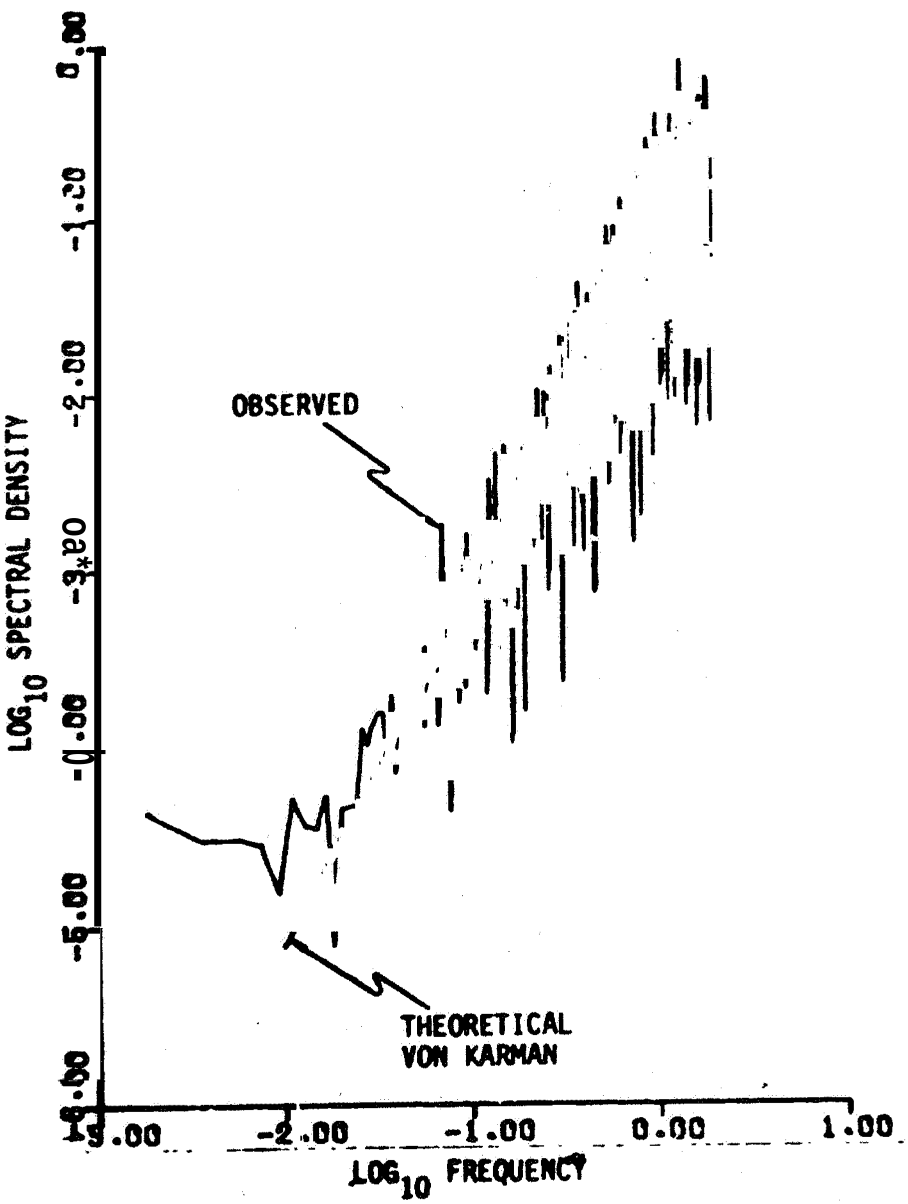

Figure A-25. $\partial u_3/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #1

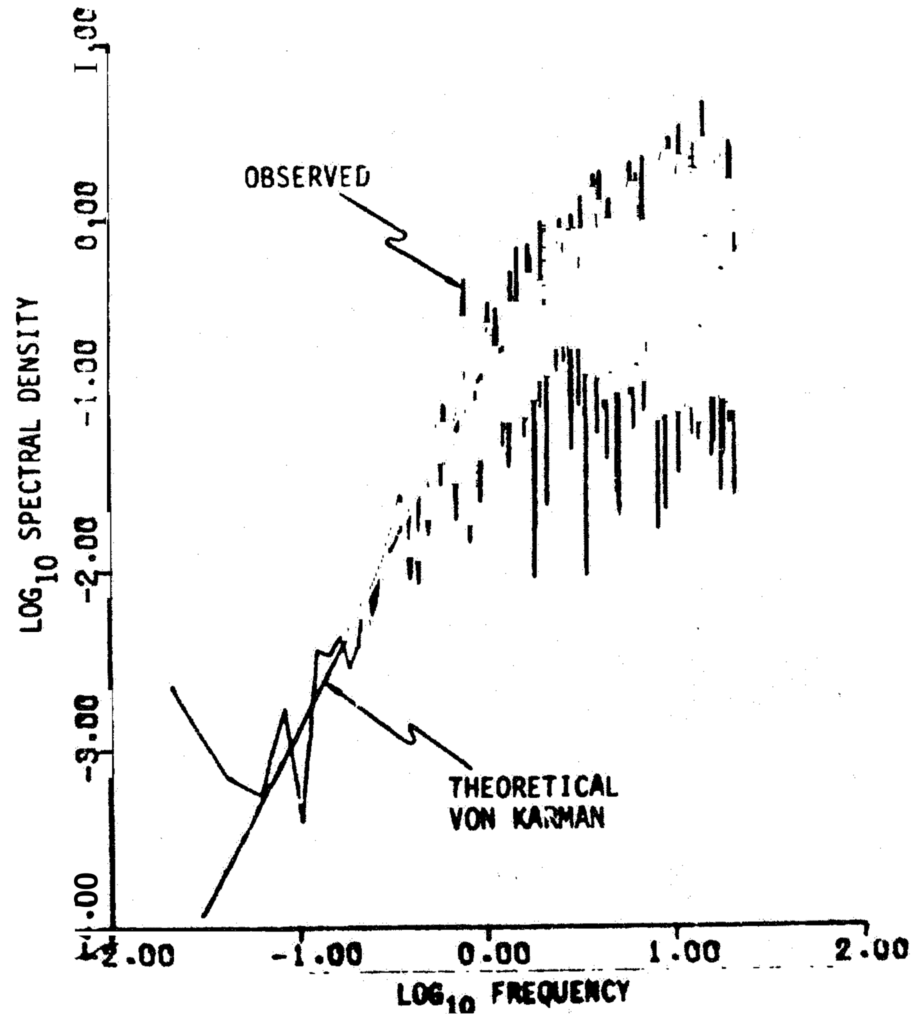

Figure A-26. $\partial u_3/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #2

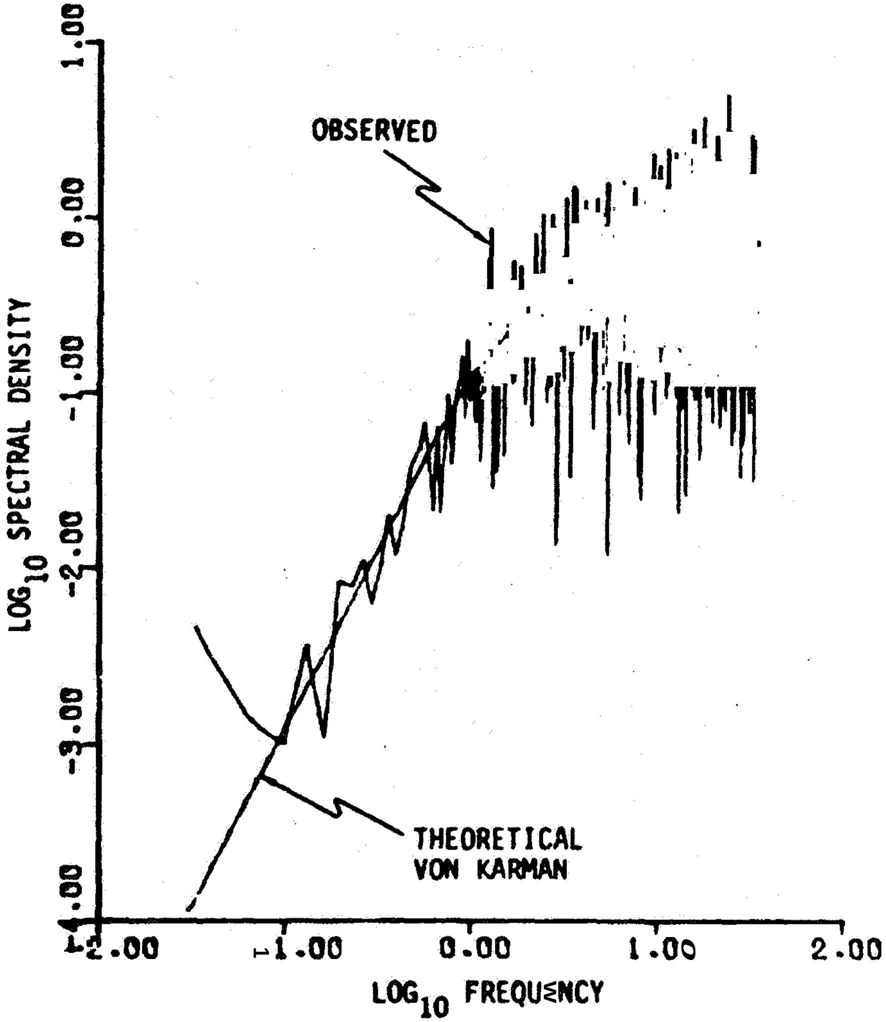

Figure A-27. $\partial u_3/\partial x_1$ - Gust Gradient Spect um, Altitude Band #3

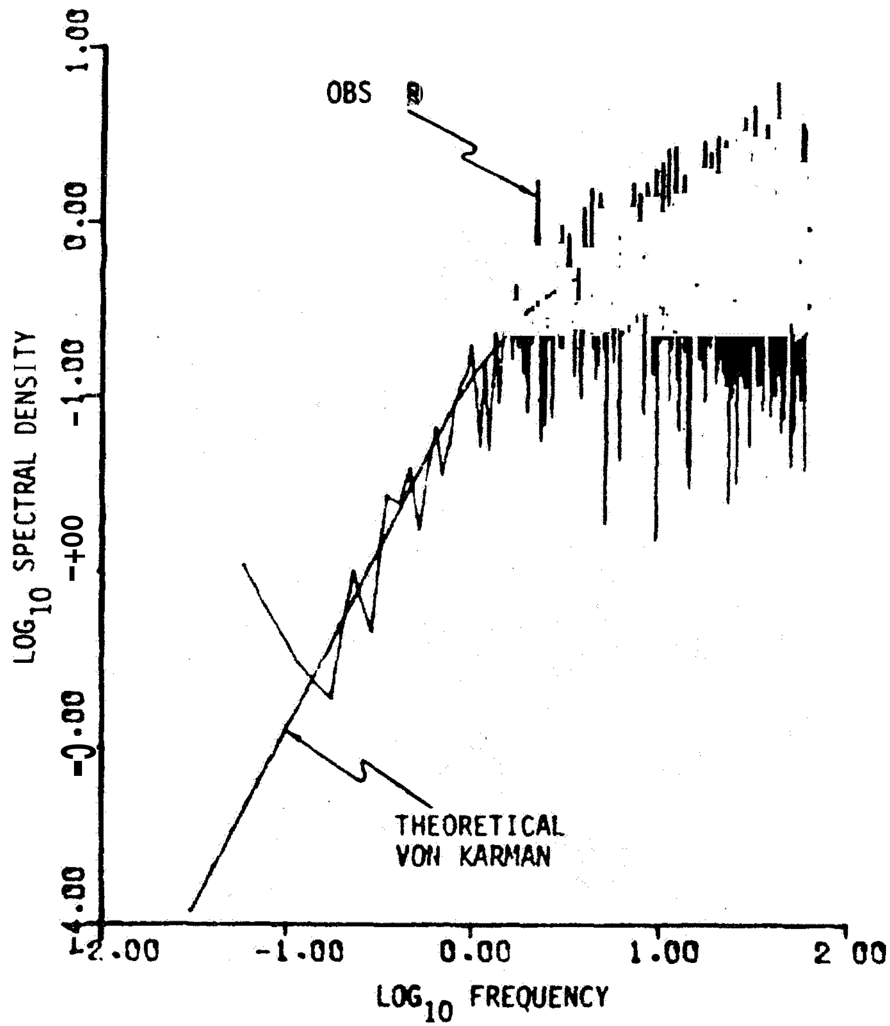

Figure A-28. $\partial u_3/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #4

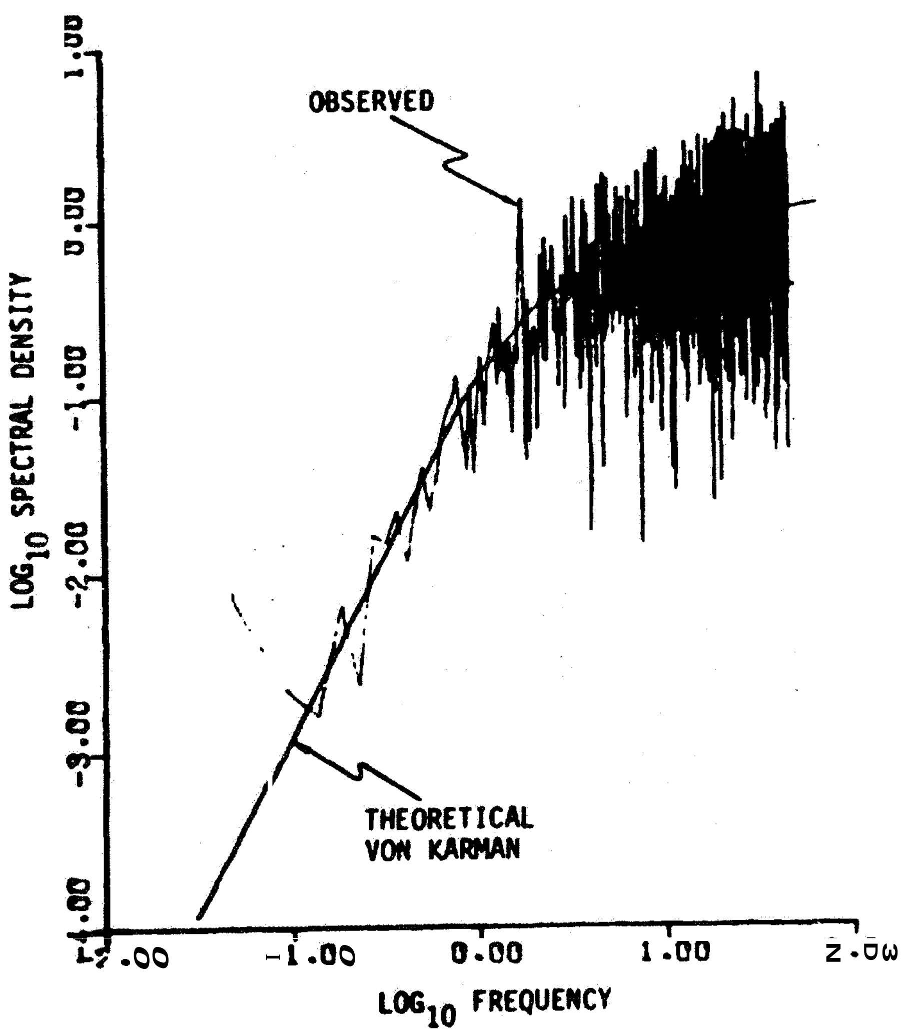

Figure A-29. $\partial u_3/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #5

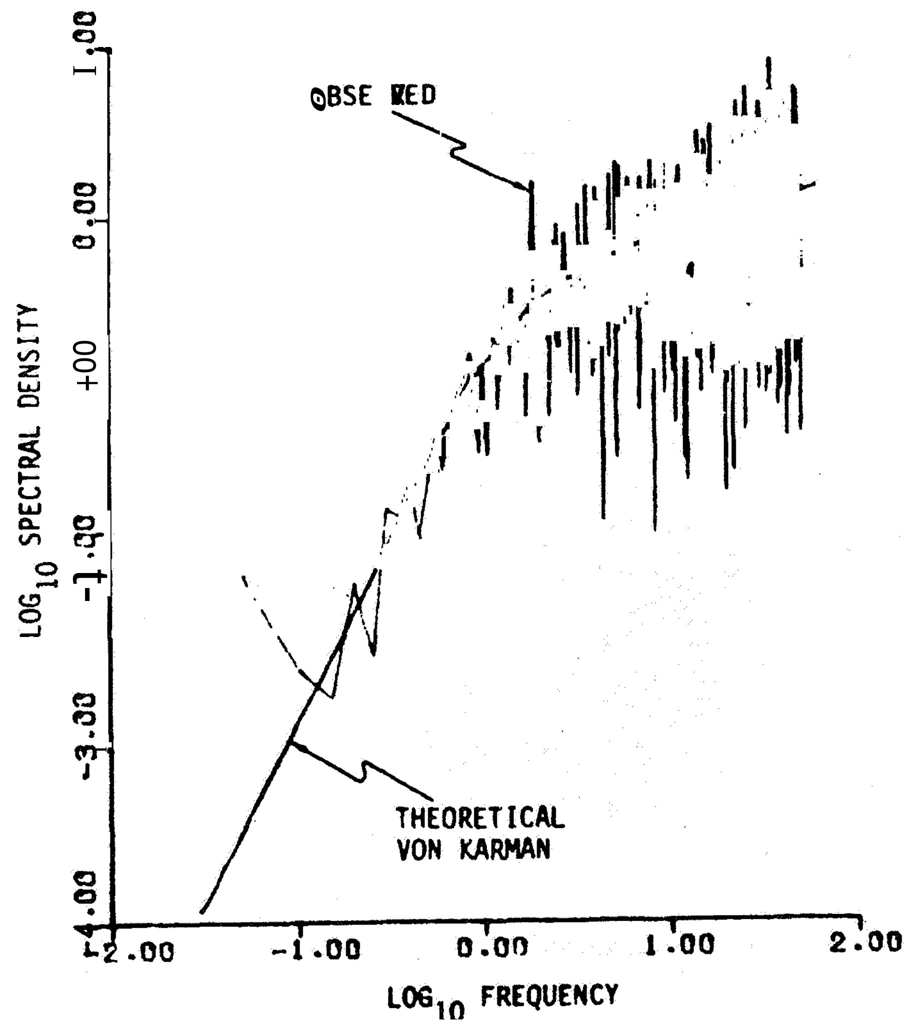

Figure A-30. $\partial u_3/\partial x_1$ - Gust Gradient Spectrum, Altitude Band #6

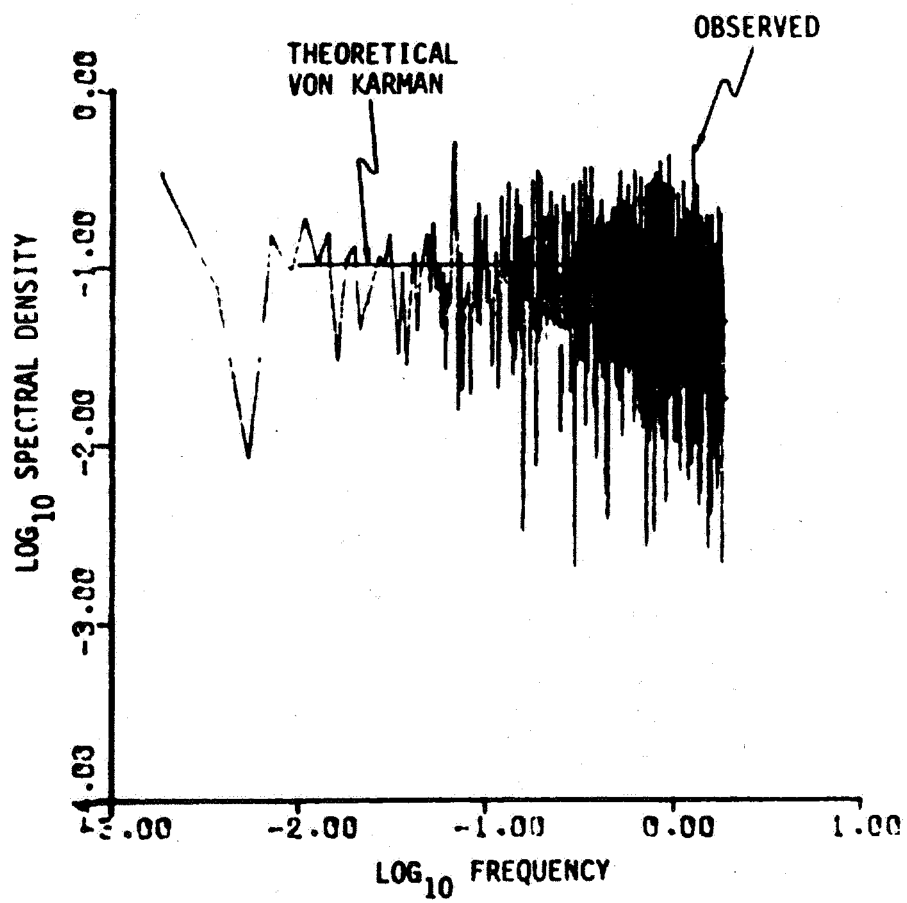

Figure A-31. $\partial u_3/\partial x_2$ - Gust Gradient Spectrum, Altitude Band #1

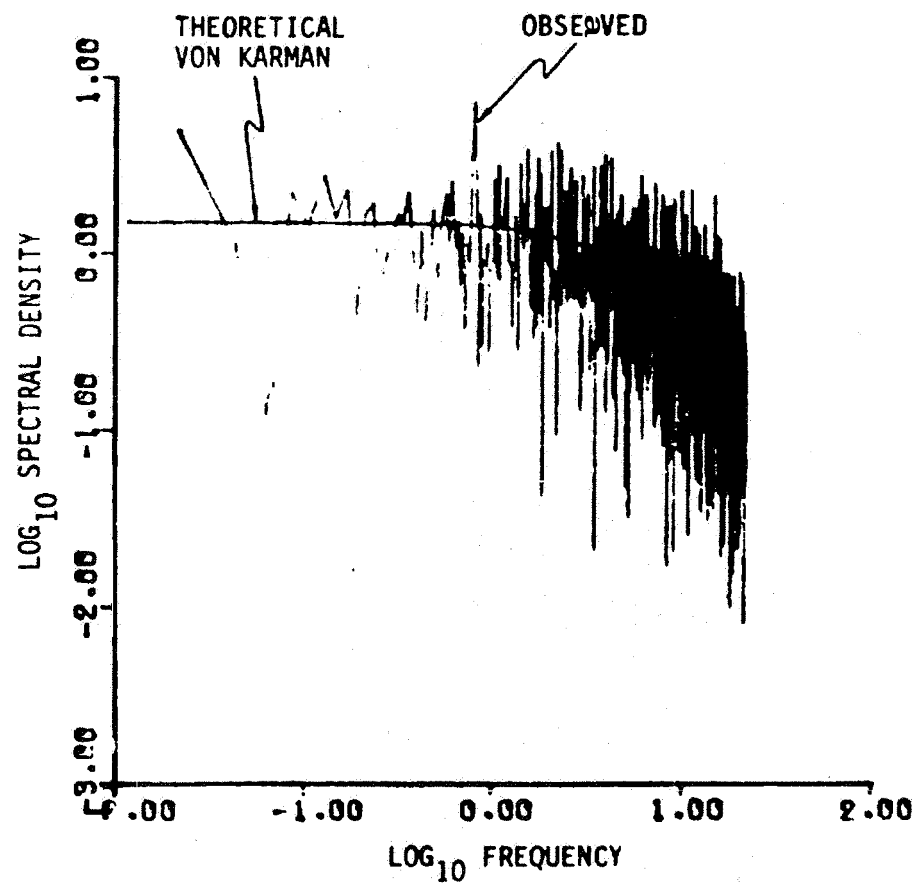

Figure A-32. $\partial u_3/\partial x_2$ - Gust Gradiemt Spect um, Altitudc Band #2

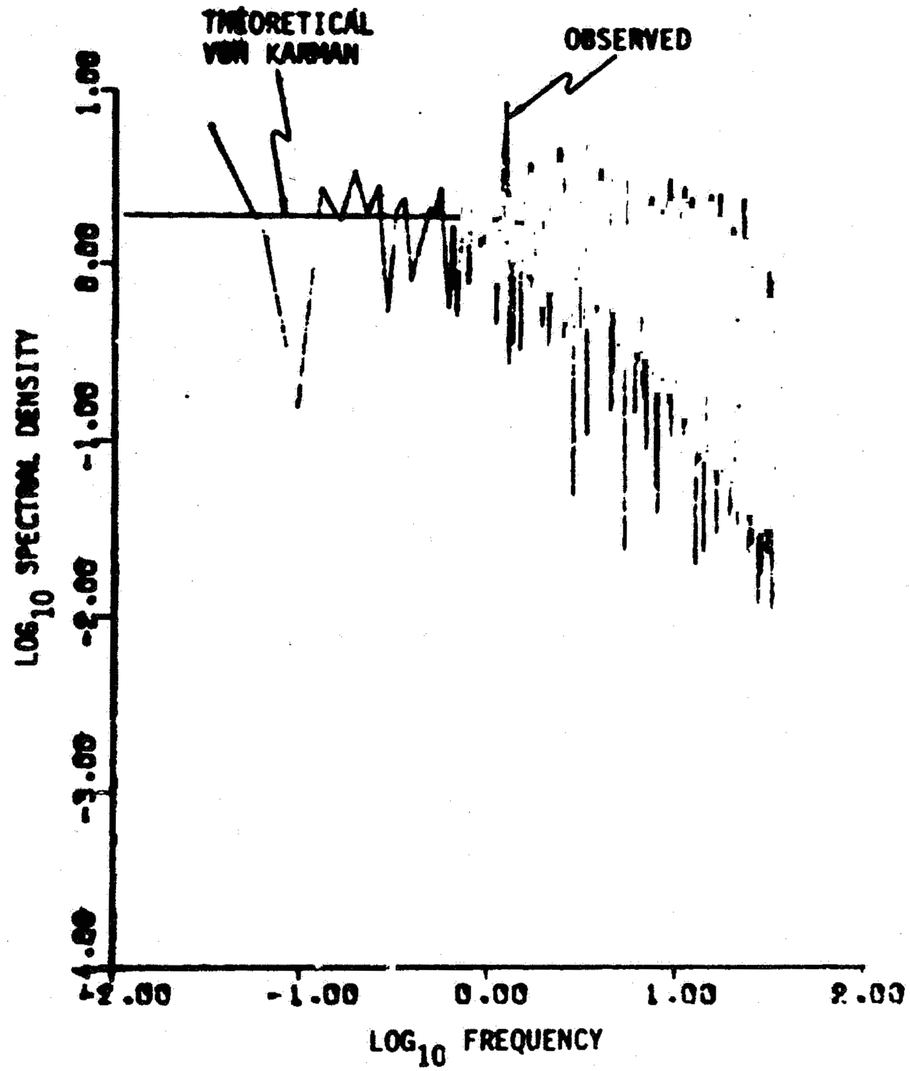

Figure A-33. $\partial u_3/\partial x_2$ - Gust Gradient Spectrum, Altitude Band #3

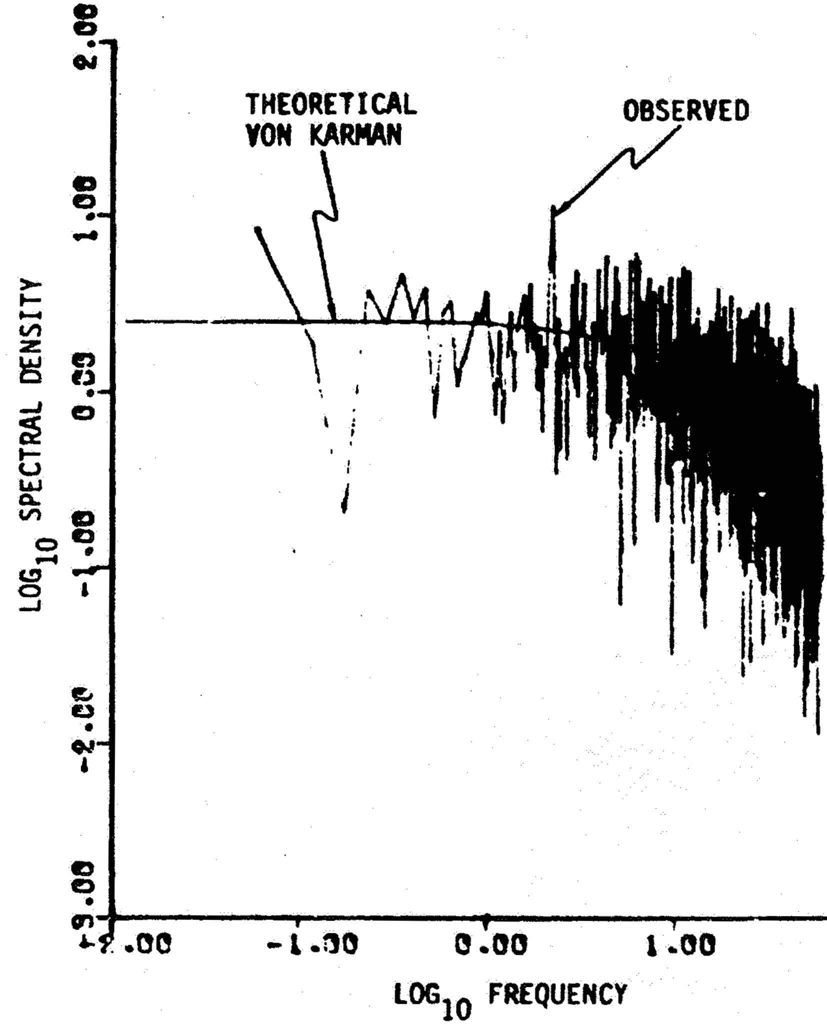

Figure A-34. $\partial u_3/\partial x_2$ - Gust Gradient Spectrum, Altitude Band #4

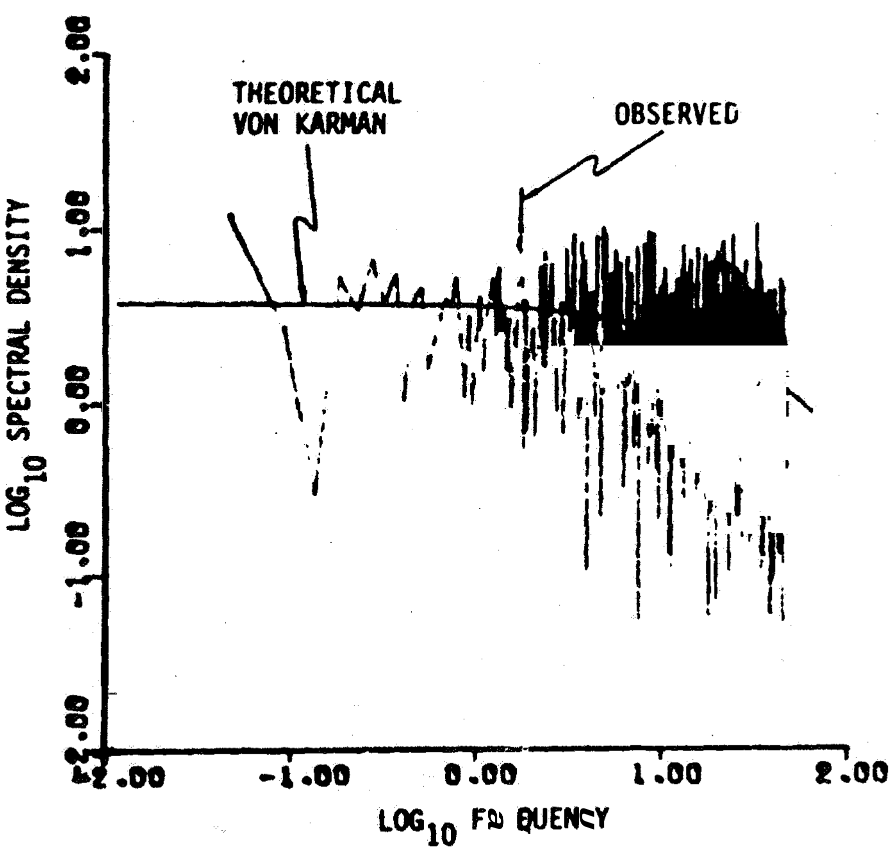

Figure A-35. $\partial u_3/\partial x_2$ - Gust Gradient Spectrum, Altitude Band #5

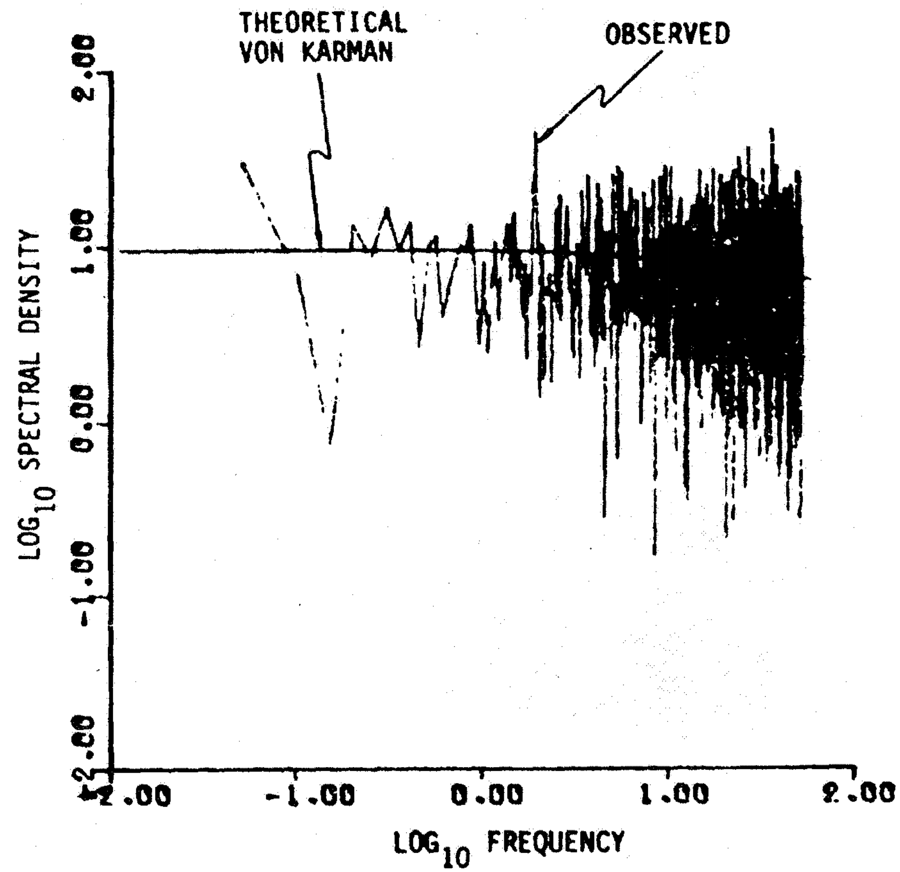

Figure A-36. $\partial u_3/\partial x_2$ - Gust Gradient Spectrum, Altitude Band #6

APPENDIX B

STATISTICAL ANALYSIS OF SIMULATED TURBULENCE

By means of standard statistical analysis procedures each of the SSTT has been analyzed to determine its mean value, standard deviation. and probability density distribution*. The resulting mean values are presented in Table B-1 while Table B-2 contains the resulting standard deviations. As expected all mean values were near zero. The standard deviations represent the square root of the energy content. The ratio of the theoretical energy content (From Table 2-3) to the square of the corresponding standard deviation (from Table B-2) is presented in Table B-3. The agreement appears quite satisfactory.

The gust and gust gradient probability density distributions are presented in Figures B-1 through B-36 in accordance with Table B-4. In each figure the corresponding theoretical normal distribution is also presented. The results indicate that both the gust and gust gradient time series are very close to normal distributions.

TABLE B-1. MEAN VALUE OF GUST AND GUST GRADIENTS

SERIES TYPE	ALTITUDE BAND					
	1	2	3	4	5	6
u_1	-.019295	-.042050	-.051852	-.088142	-.0455	-.0464
u_2	-.010671	-.029576	-.0371	-.049431	-.0428	-.0441
u_3	-.006806	-.029652	-.037043	-.049370	-.043788	-.046637
$\partial u_2/\partial x_1$	-.000002	-.001572	-.002794	-.005628	-.172152	-.206385
$\partial u_3/\partial x_2$	-.000001	-.001591	-.002798	-.005649	-.004293	-.004893
$\partial u_3/\partial x_1$	-.005760	-.073072	-.103823	-.160303	-.171448	-.288178

*The statistical analysis involved the first 4096 terms of each time series except for bands 5 and 6 for the u_1 and u_2 gusts. For these cases 8192 terms were used.

TABLE B-2. STANDARD DEVIATION OF GUST AND GUST GRADIENTS

SERIES TYPE	ALTITUDE BAND					
	1	2	3	4	5	6
u_1	.788959	.927098	.946351	.964271	.99888	.99996
u_2	.707845	.925201	.94619	.964152	,99764	.99863
u_3	.524571	.915606	.938552	.958985	.961845	,967651
$\partial u_2/\partial x_1$	.766627	?. 625937	4.976118	7.356808	41.717292	08.052734
$\partial u_3/\partial x_2$	.390512	3.488677	4.758426	7.037516	6.458092	7.216648
$\partial u_3/\partial x_1$	.394539	3.508280	4.784378	7.075349	9.778736	19.790119

TABLE B-3. RATIO OF THE THEORETICAL ENERGY CONTENT* TO THE SQUARE OF THE OBSERVED STANDARD DEVIATION†

SERIES TYPE	ALTITUDE BAND					
	1	2	3	4	5	6
u_1	1.0001	1.0000	1.0000	1.0000	.9999	1.0001
u_2	.9999	1.0000	.9999	1.0000	1.0000	1.0000
u_3	1.0001	1.0000	1.0000	1.0001	1.0000	.9999
$\partial u_2/\partial x_1$	1.0000	1.0000	1.0000	1.0000	.9998	1.0000
$\partial u_3/\partial x_2$	1.0000	1.0000	1.0000	1.0000	1.0001	1.0000
$\partial u_3/\partial x_1$	1.0002	1.0000	1.0000	1.0000	1.0000	.9999

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*Theoretical energy content taken from Table 2-3.

†Observed standard deviation taken from Table B-2.

TABLE 8-4. MATRIX OF STATISTICAL ANALYSIS FIGURES

SERIES TYPE	ALTITUCE BAND					
	1	2	3	4	5	6
u_1	8-1	B-2	8-3	B-4	B-5	B-6
u_2	B-7	8-8	8-3	B-10	B-11	B-12
u_3	8-13	B-14	B-15	B-16	B-17	B-18
$\partial u_2/\partial x_1$	B-19	6-20	8-21	B-72	3-23	8-24
$\partial u_3/\partial x_1$	B-25	8-26	3-27	8-28	8-29	8-30
$\partial u_3/\partial x_2$	B-31	8-32	8-33	B-34	8-35	B-36

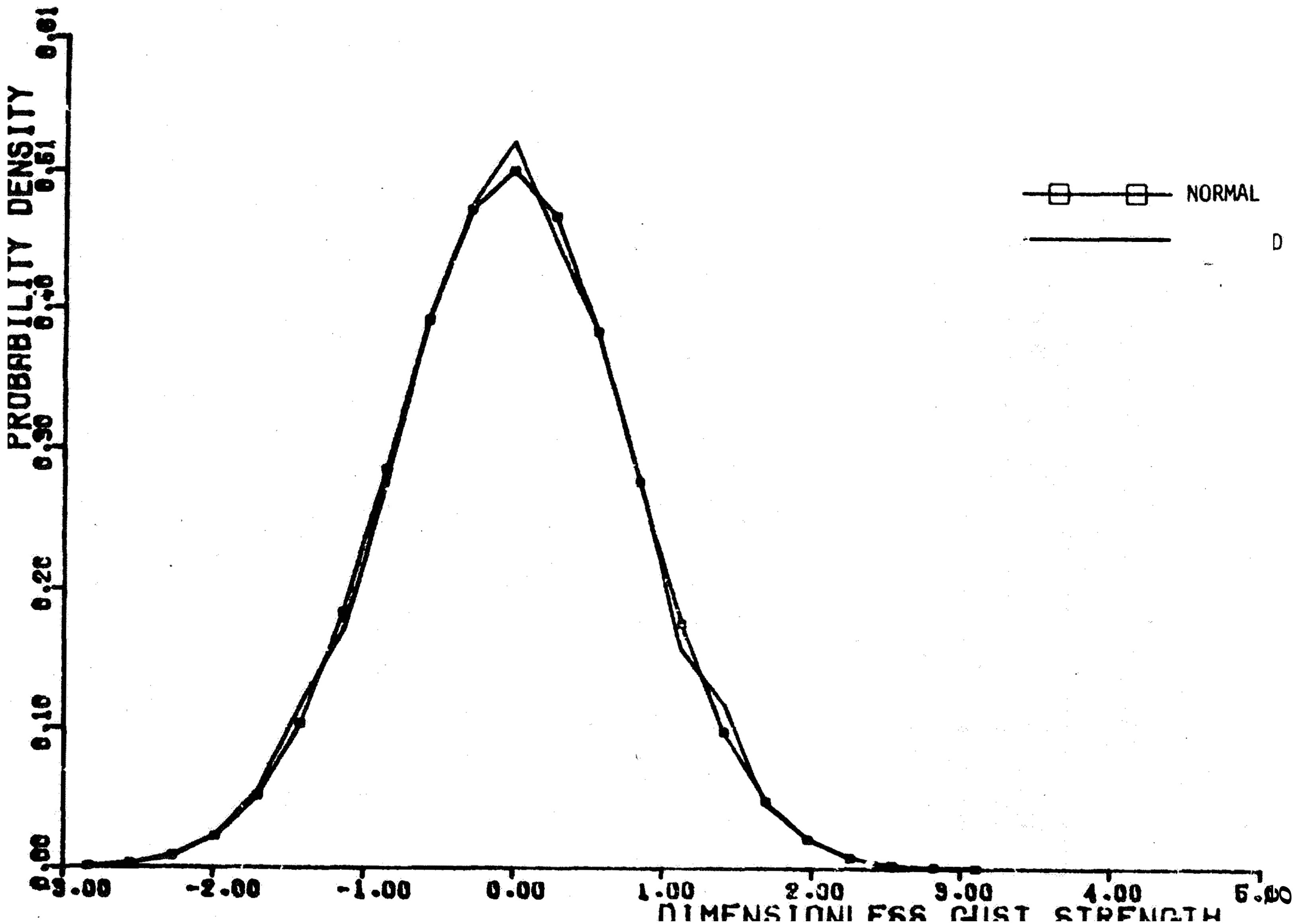

Figure B-1. u_1 - Gust Probability Density Distribution, Altitude Band #1

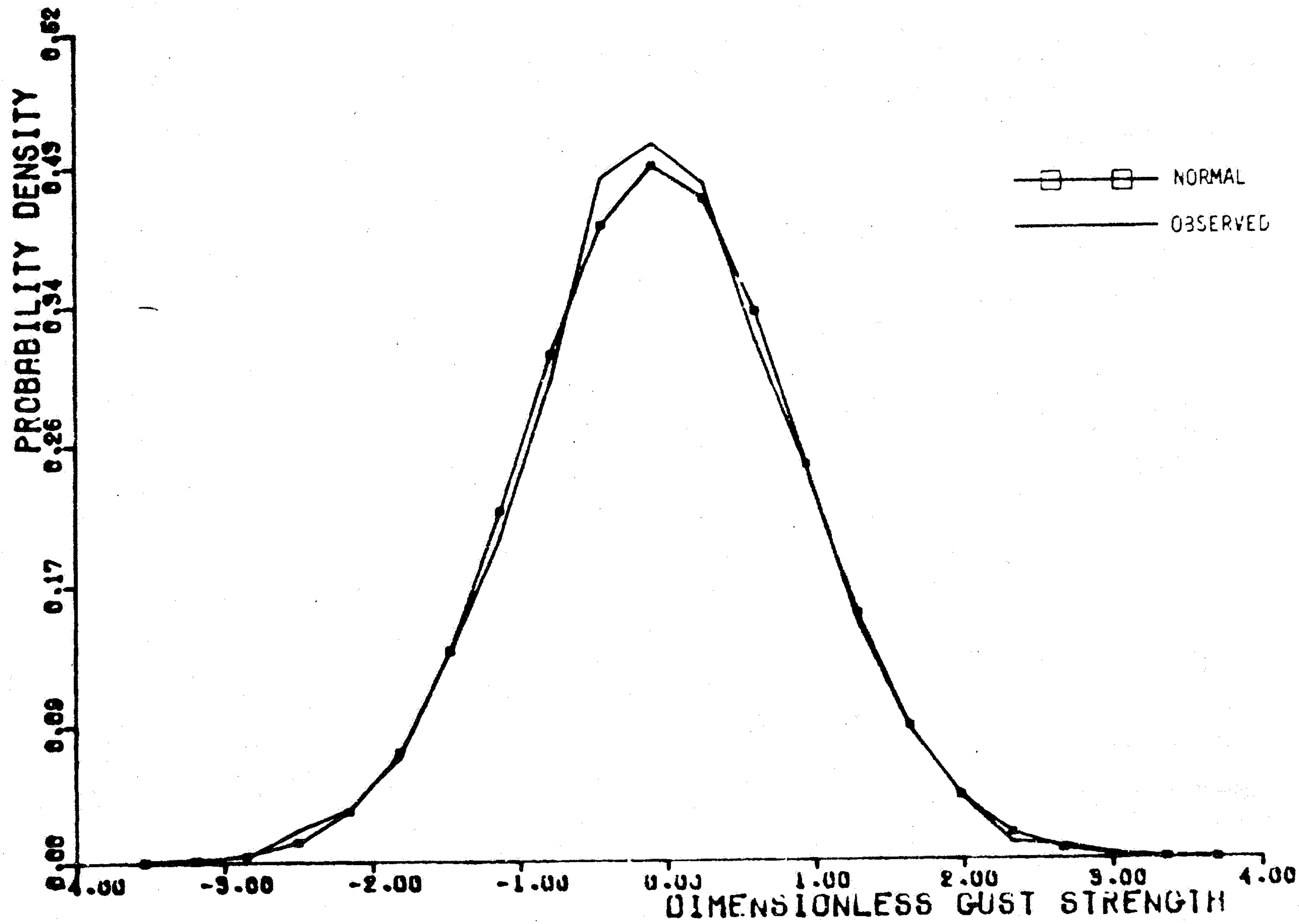

Figure B-2. u_1 - Gust Probability Density Distribution, Altitude Band #2

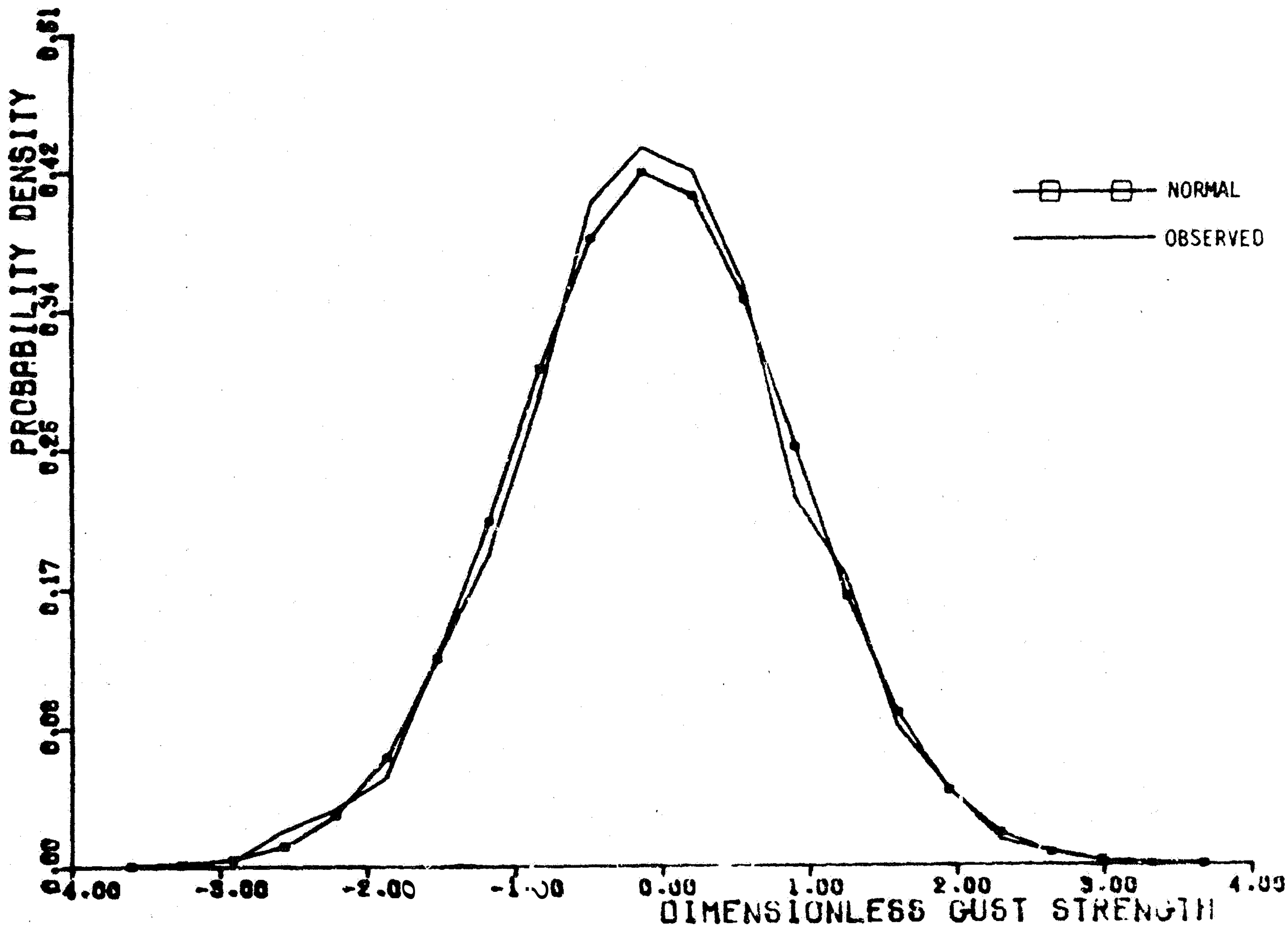

Figure B-3. u_1 - Gust Probability Density Distribution, Altitude Band 3

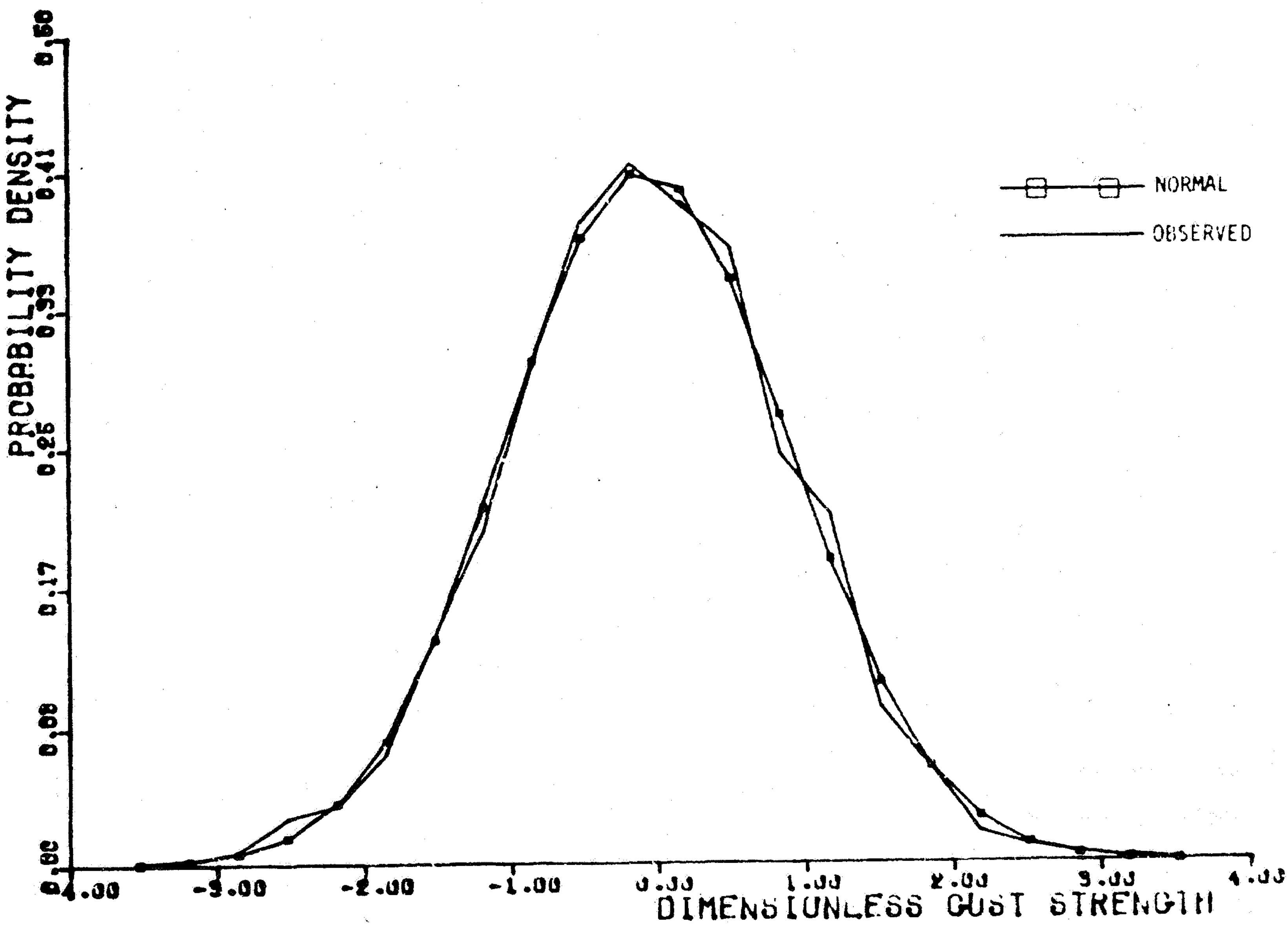

Figure B-4. u_1 - Gust Probability Density Distribution, Altitude Band 4

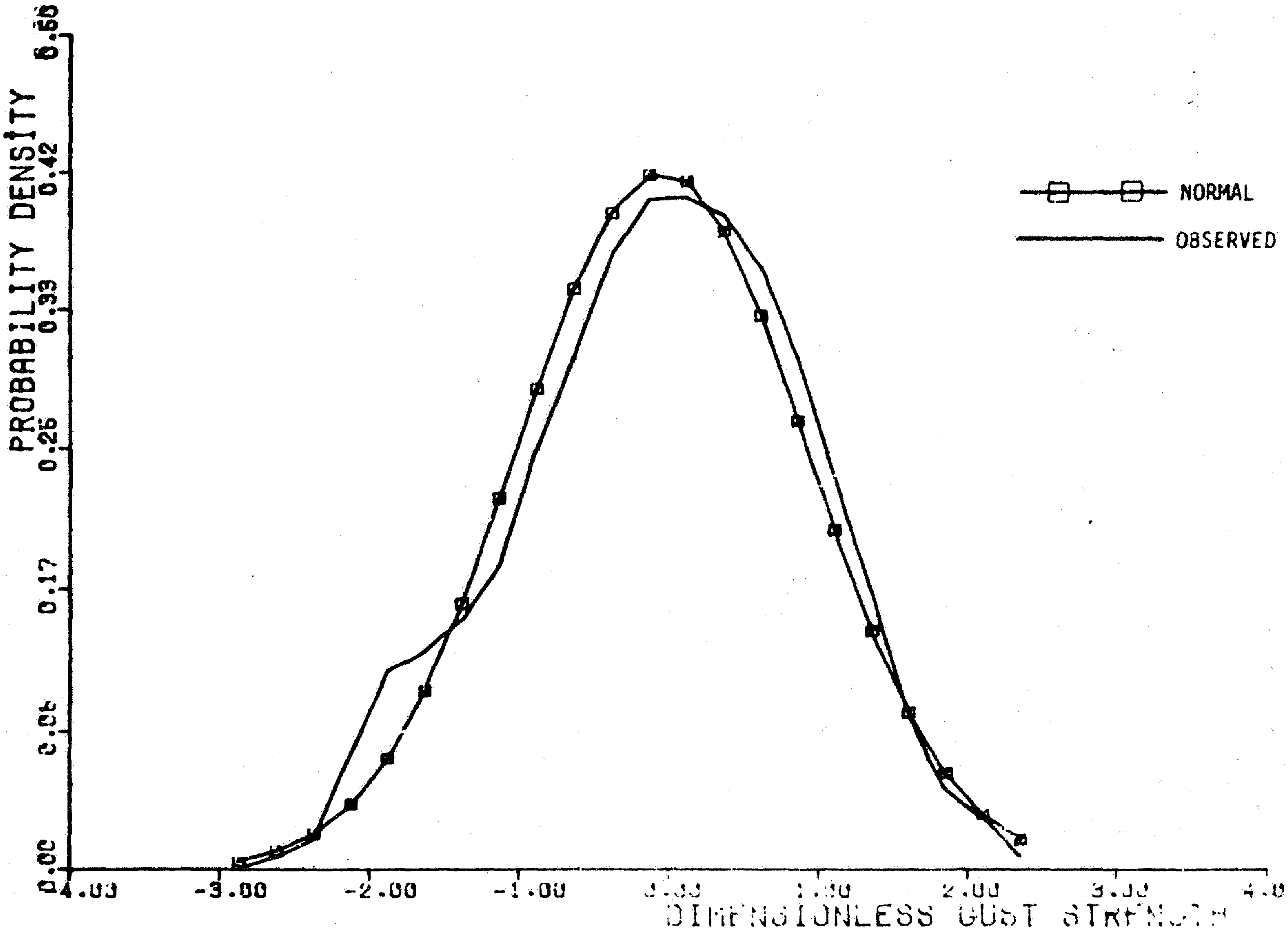

Figure 8-5. u_1 - Gust Probability Density Distribution, Altitude Band #5

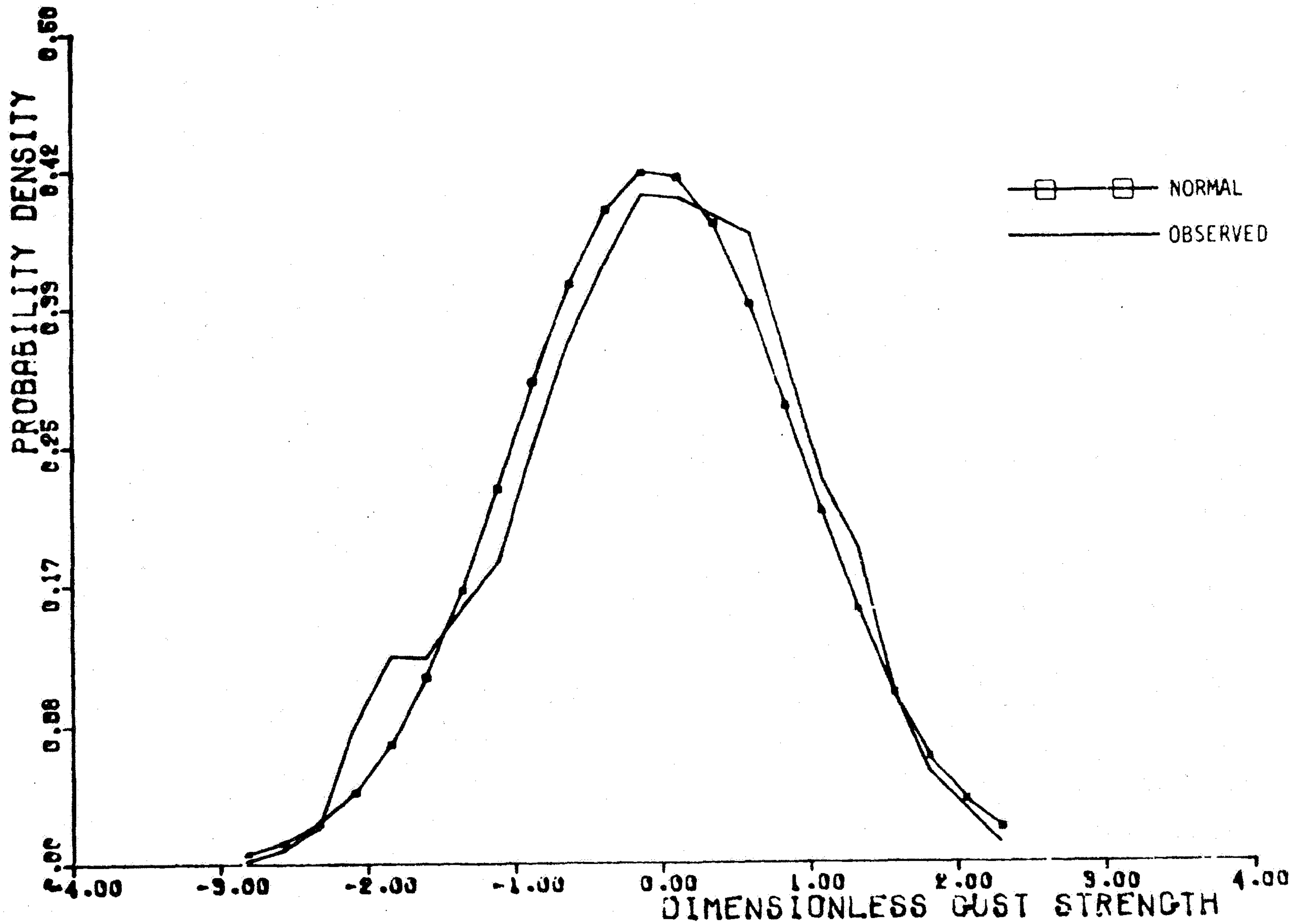

Figure B-6. u_1 - Gust Probability Density Distribution, Altitude Band #6

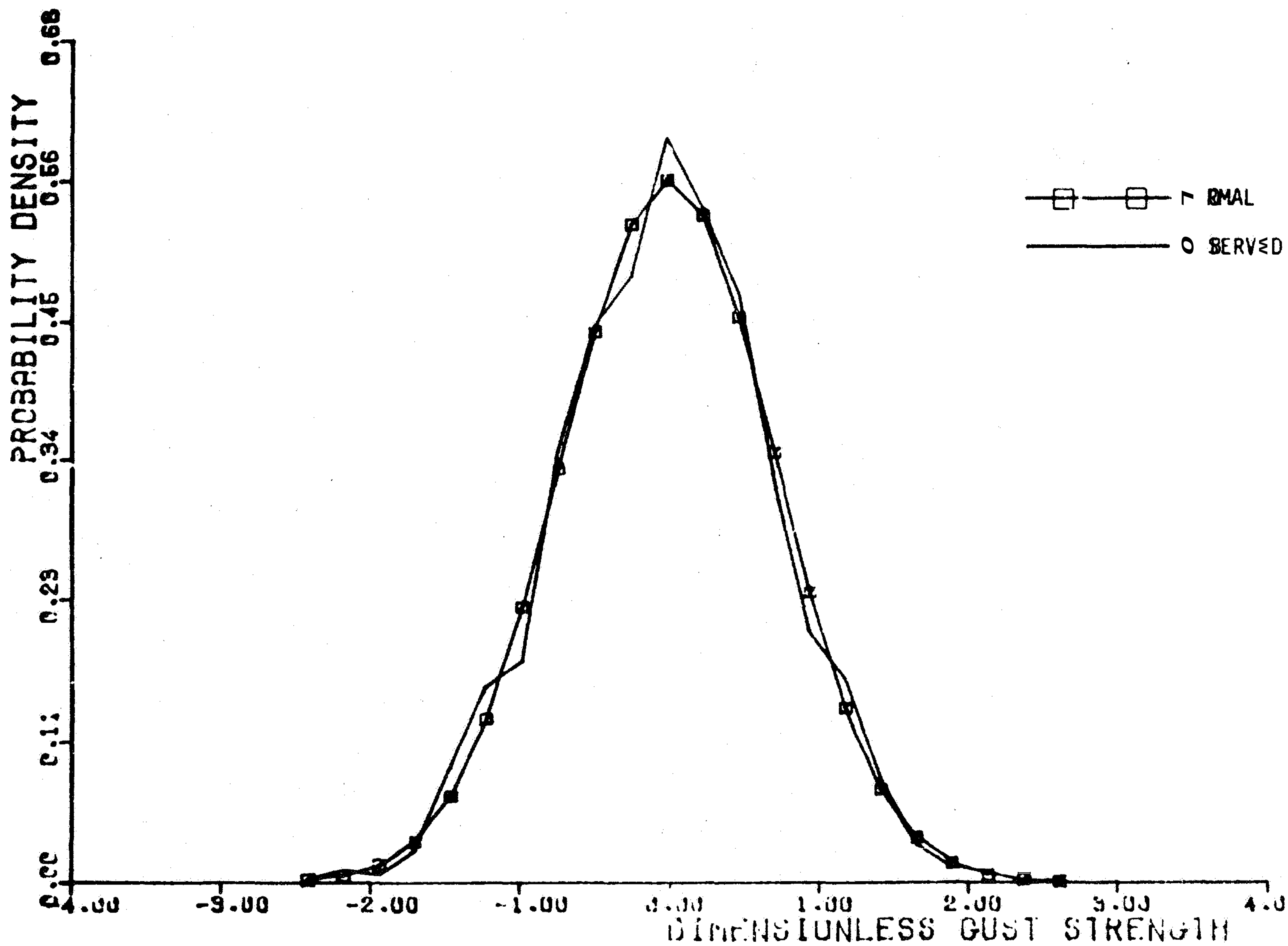

Figure B-7. u_2 - Gust Probability Density Distribution, Altitude Band #1

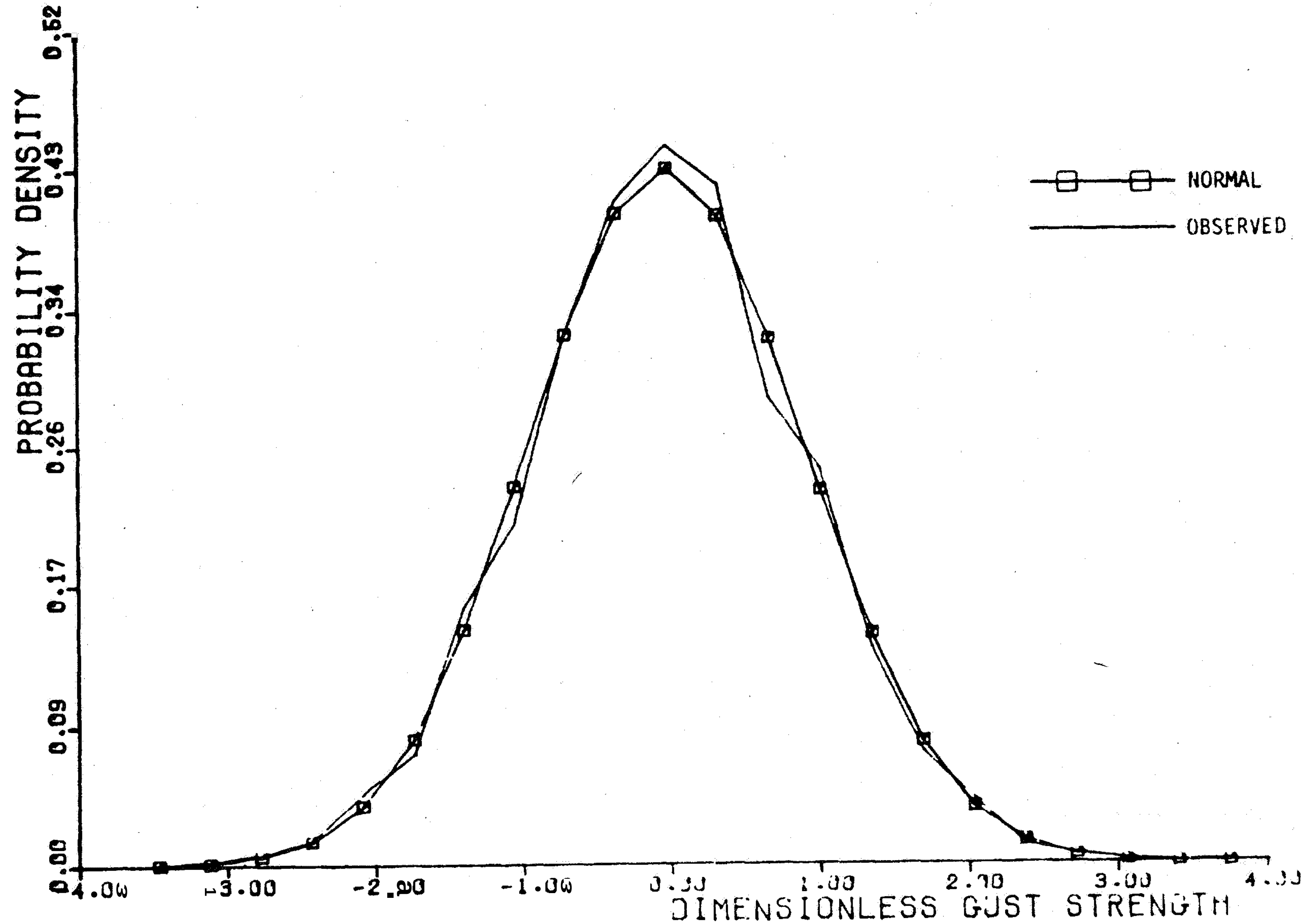

Figure B-8. u_2 - Gust Probability Density Distribution, Altitude Band #2

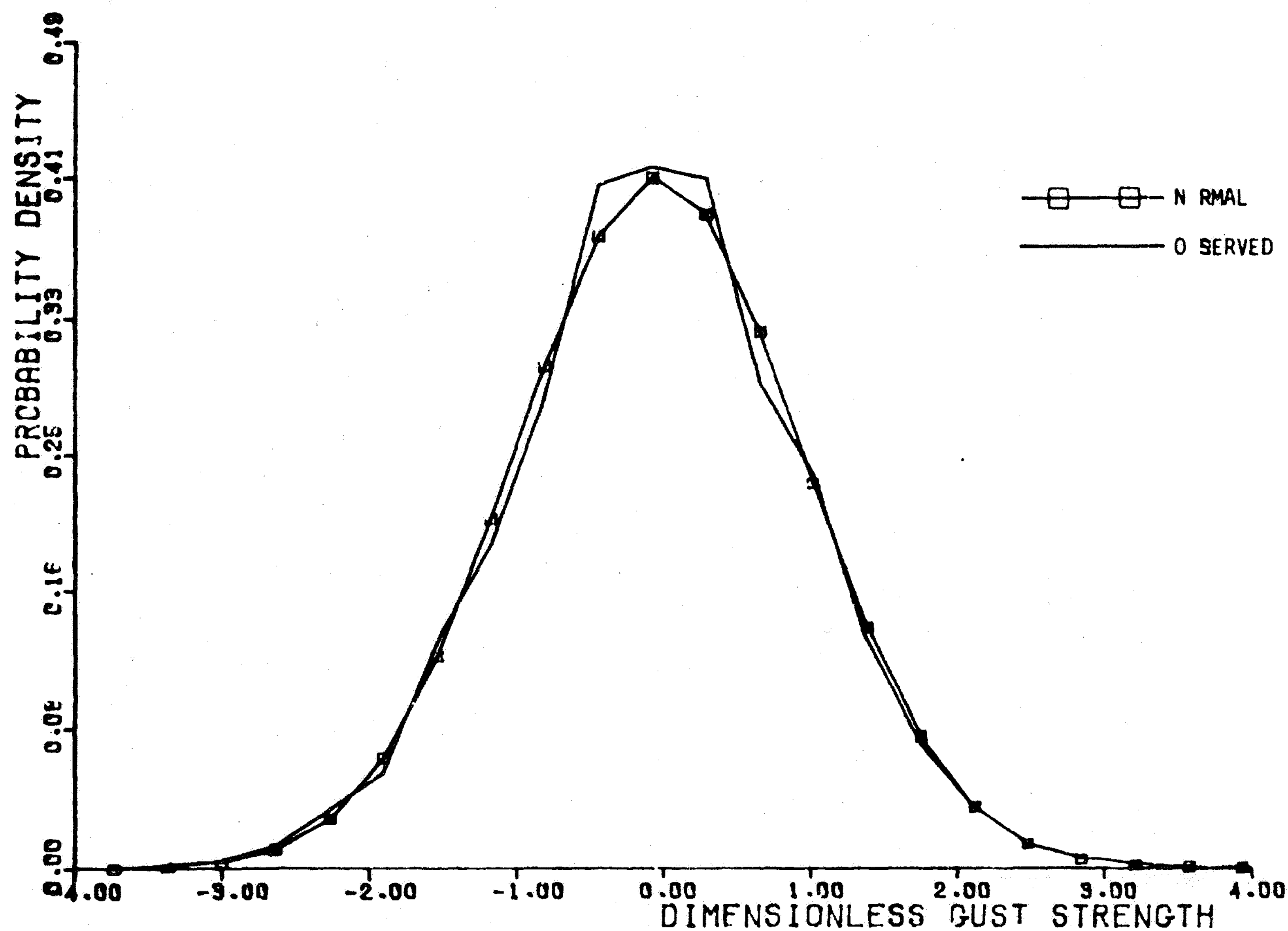

Figure B-9. u_2 - Gust Probability Density Distribution, Altitude Band #3

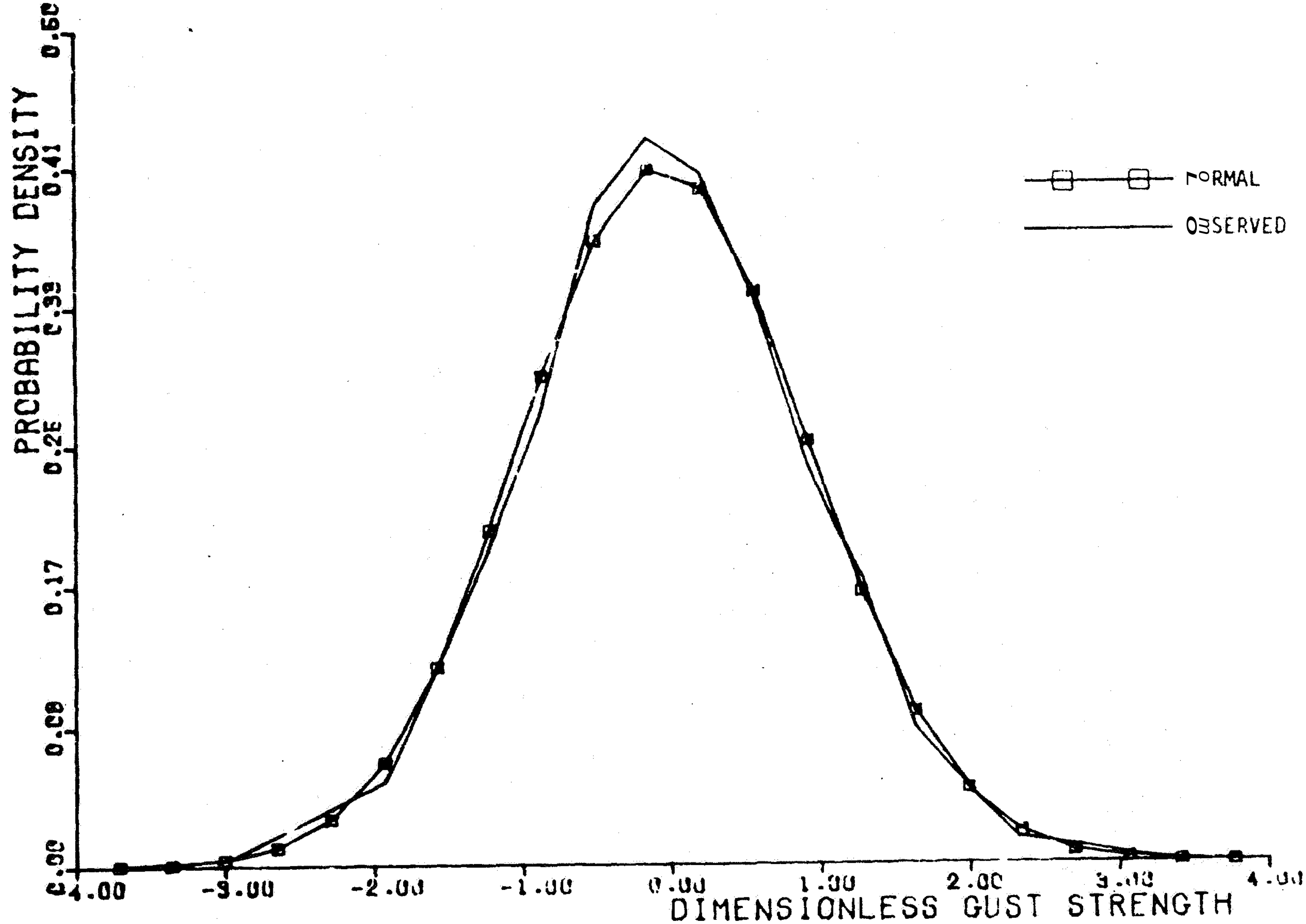

Figure B-10. u_2 - Gust Probability Density Distribution, Altitude Band #4

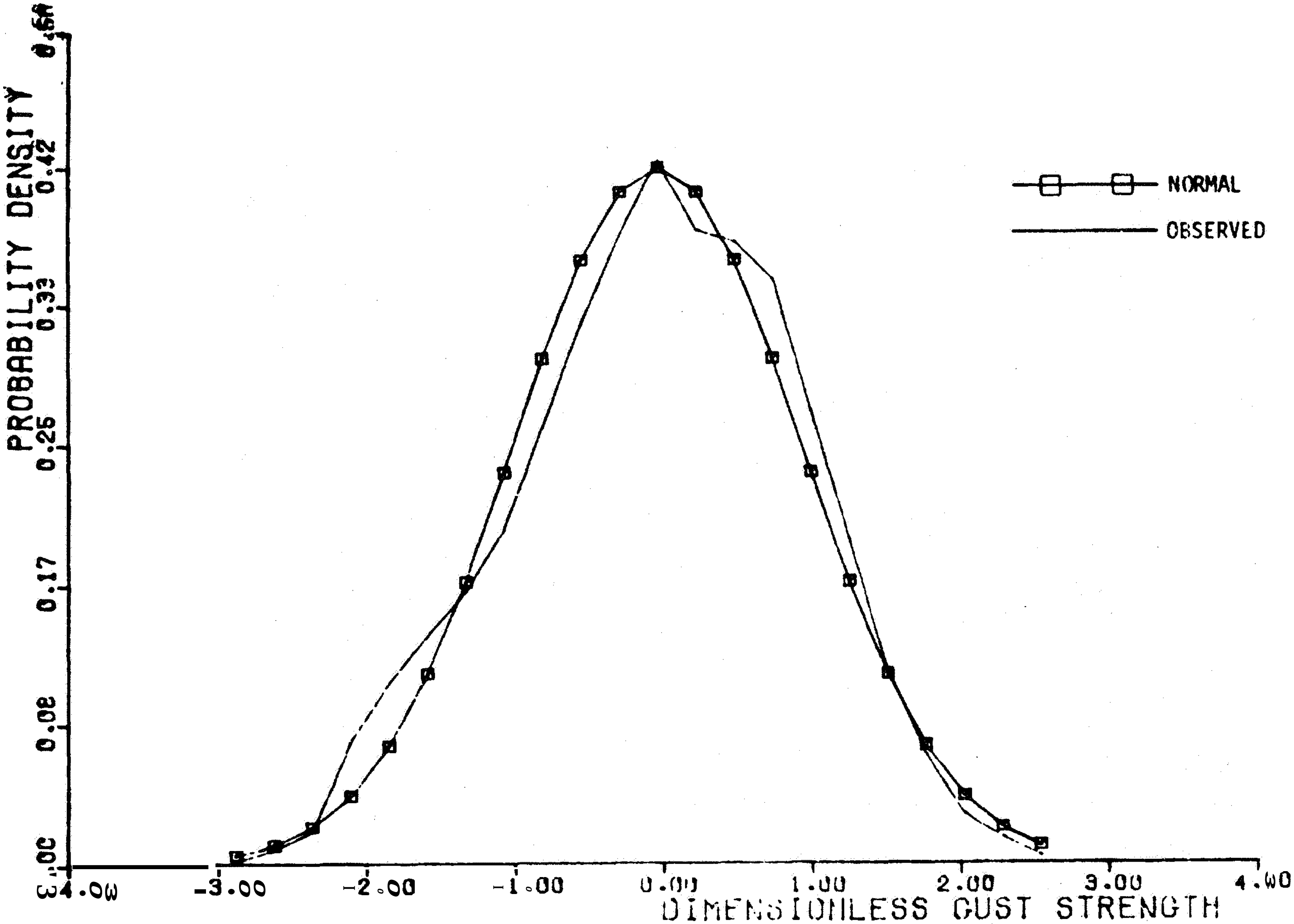

Figure B-11. u_2 - Gust Probability Density Distribution, Altitude Band #5

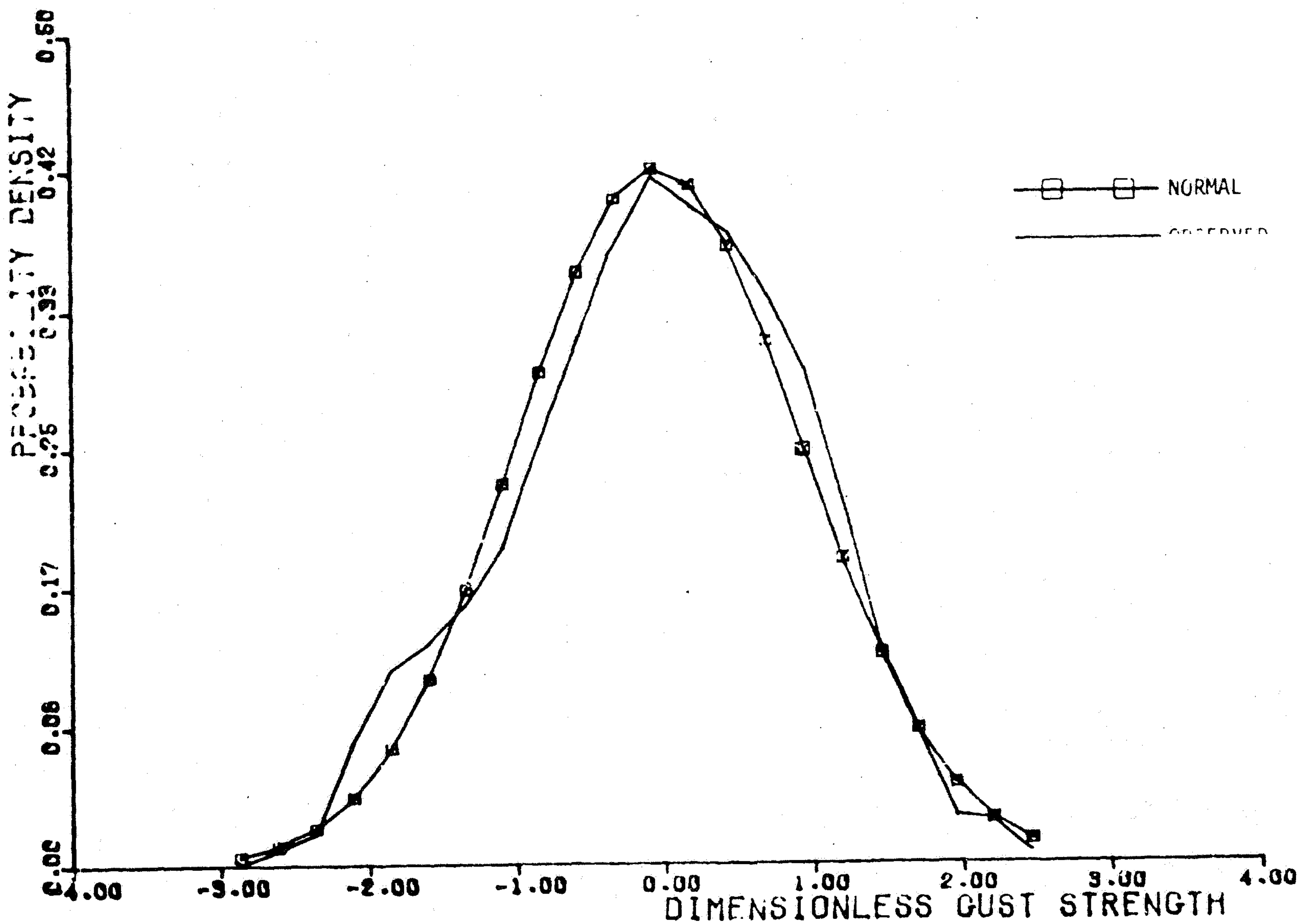

Figure B-12. u_2 - Gust Probability Density Distribution, Altitude Band #C

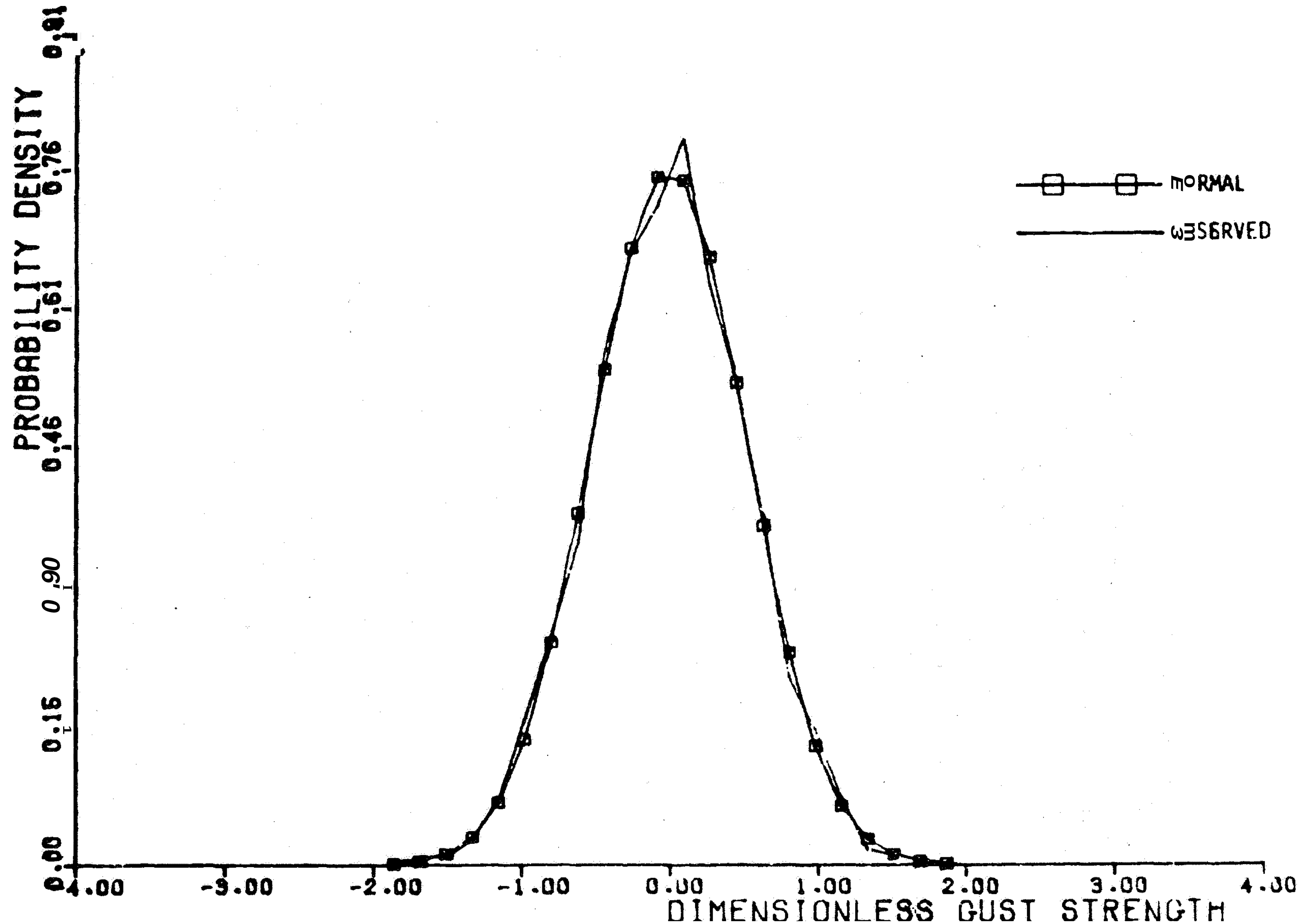

Figure B-13. u_3 - Gust Probability Density Distribution, Altitude Band #1

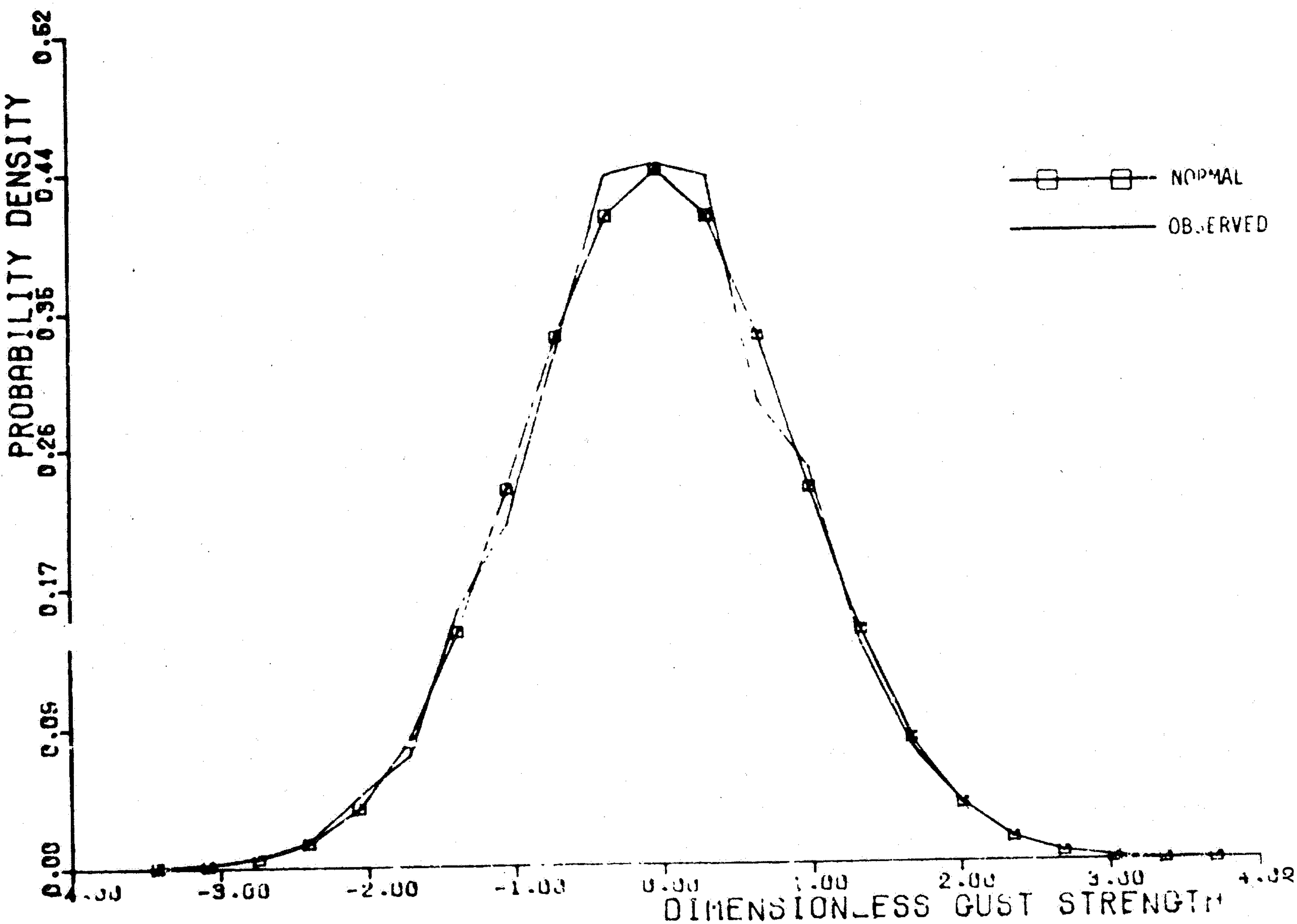

Figure 8-14. u_3 - Gust Probability Density Distribution, Altitude Band #2

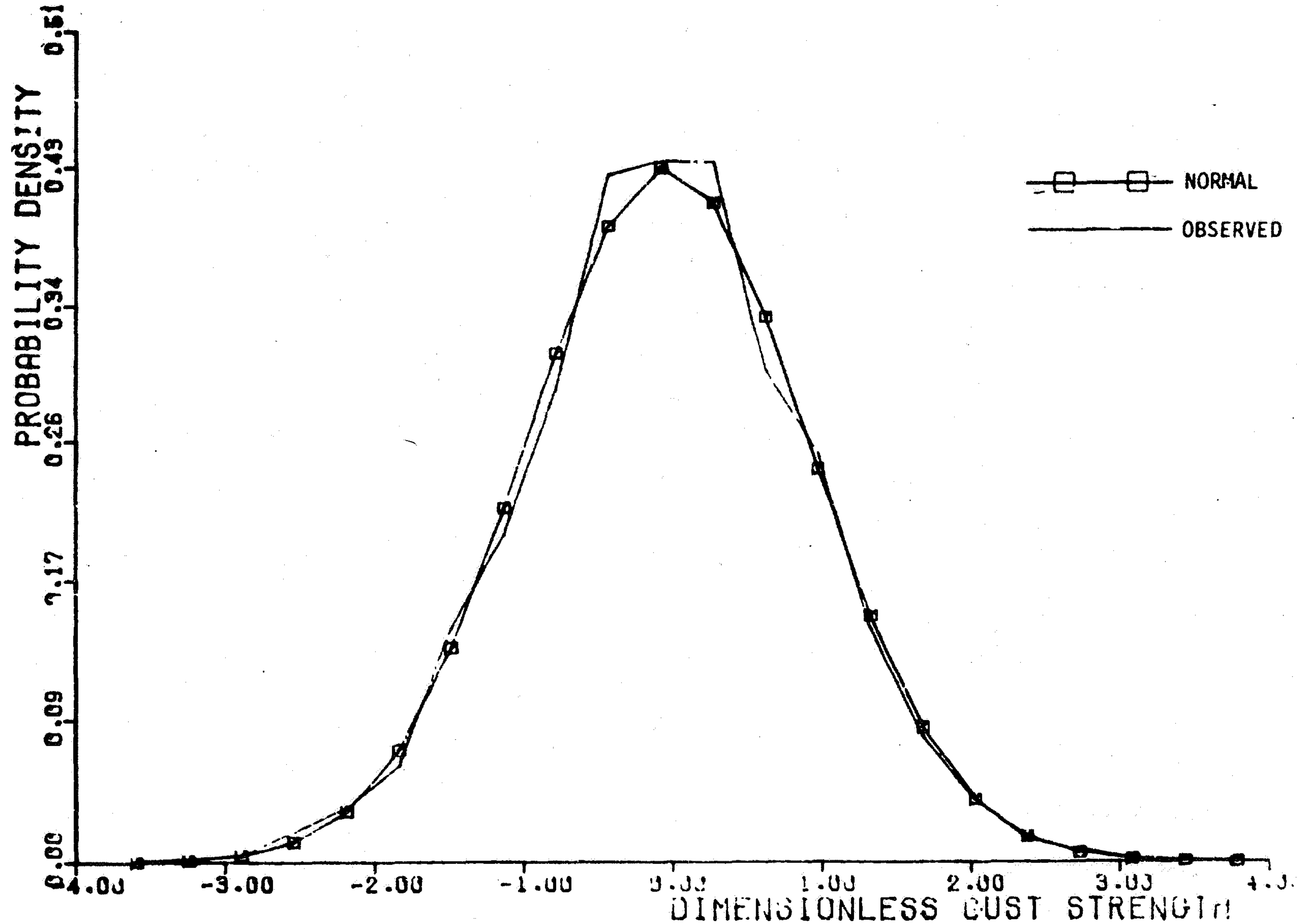

Figure B-15. u_3 - Gust Probability Density Distribution, Altitude Band #3

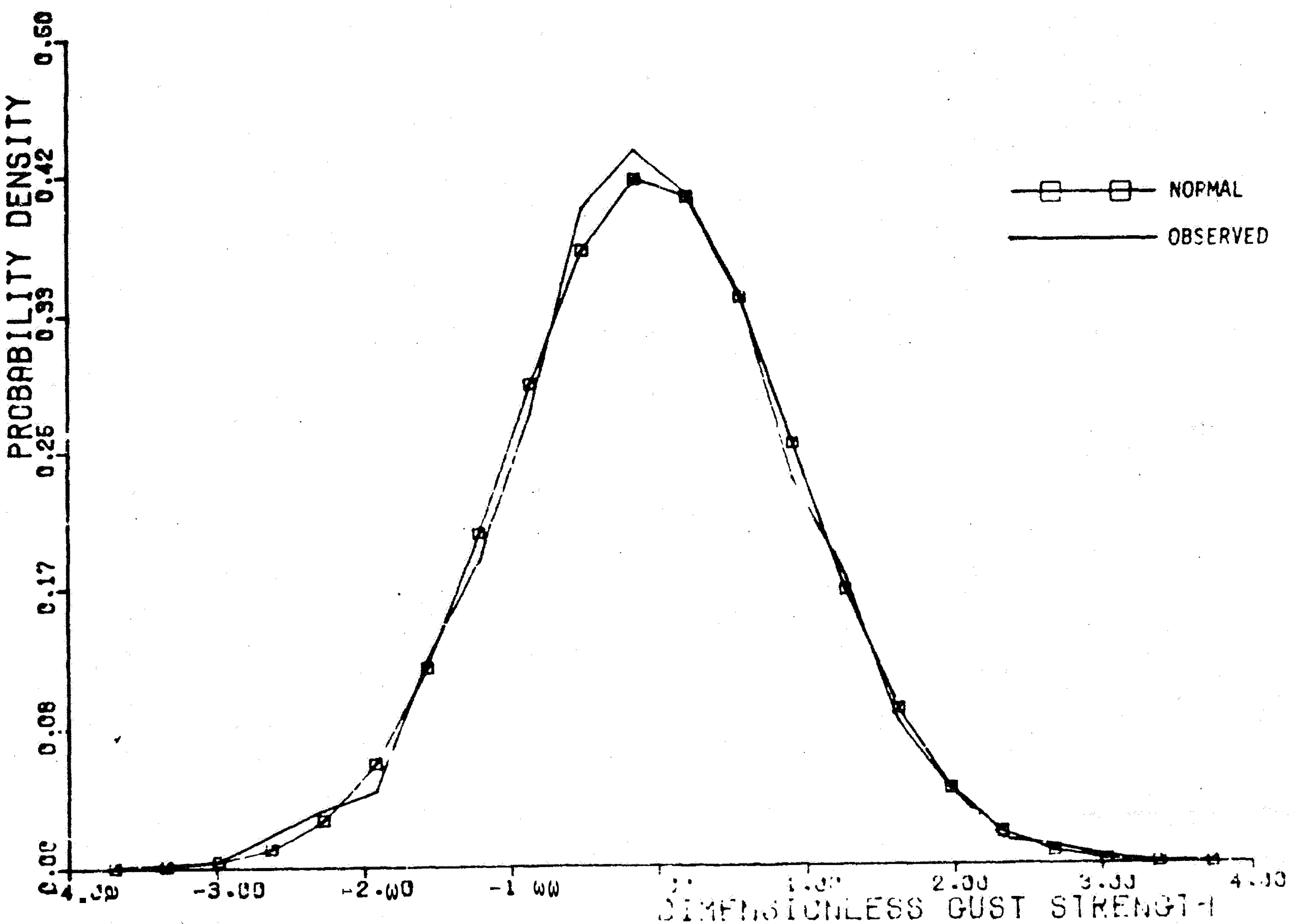

Figure B-16. u_3 - Gust Probability Density Distribution, Altitude Band #4

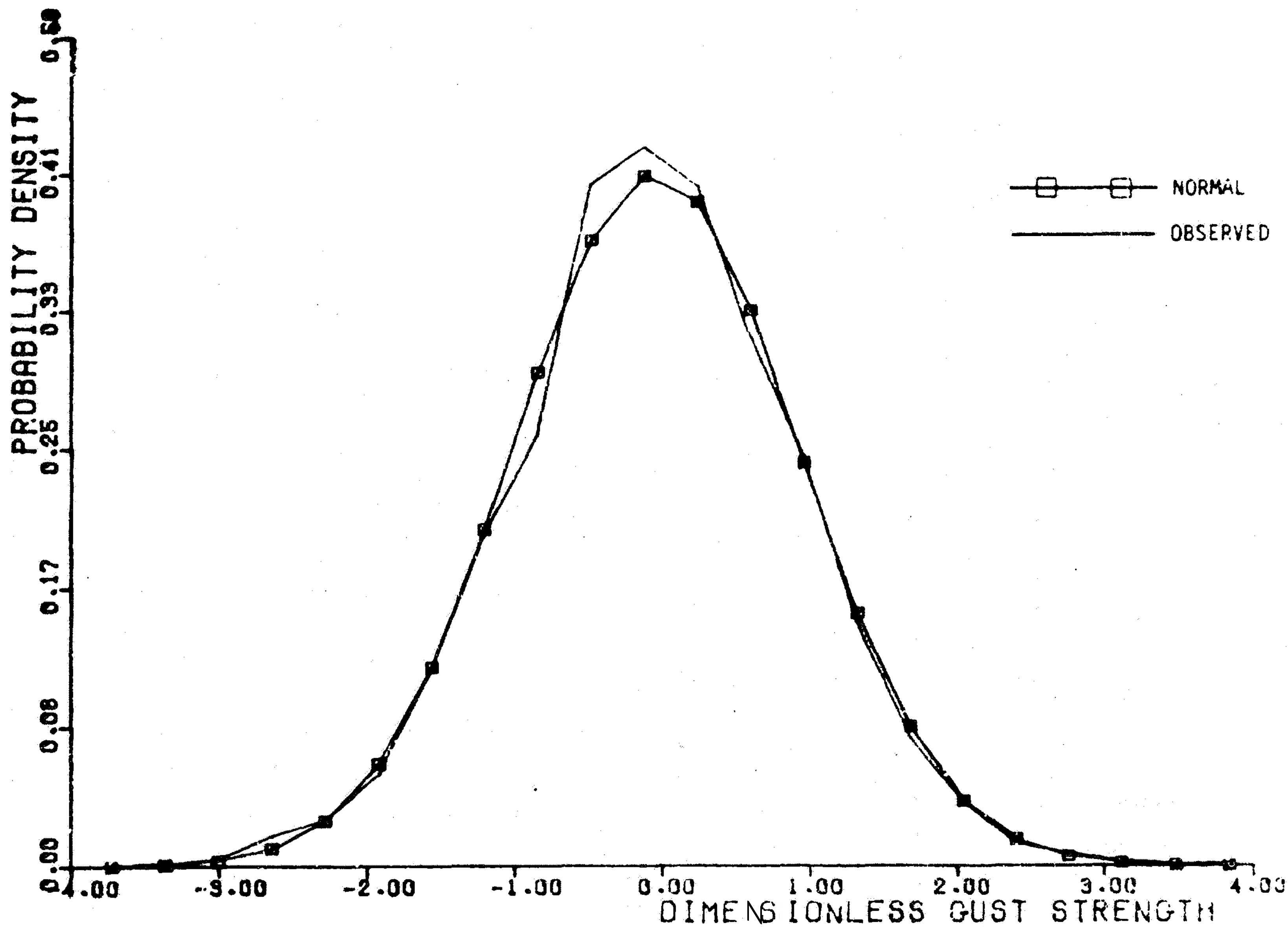

Figure B-17. u_3 - Gust Probability Density Distribution, Altitude Band #5

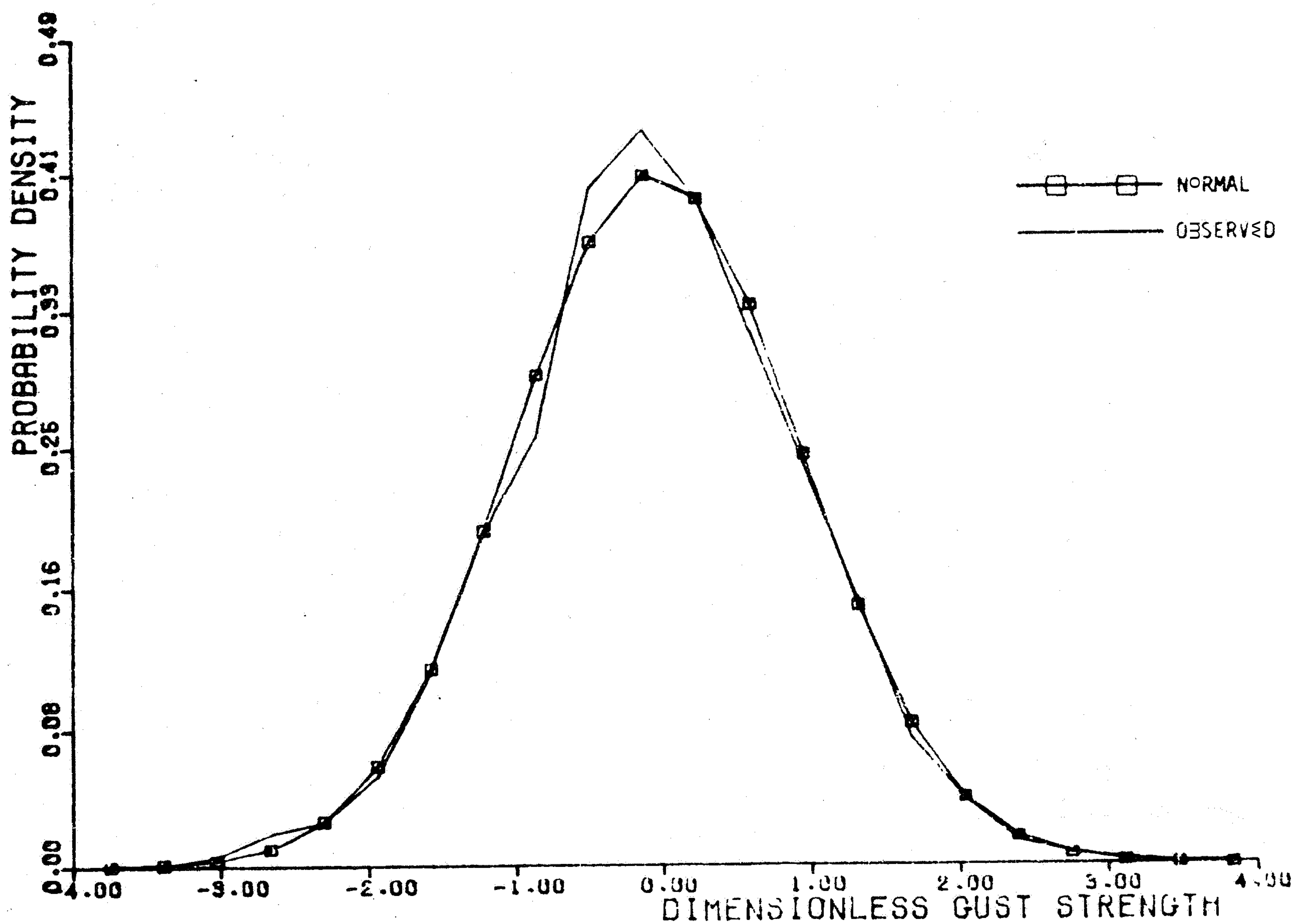

Figure B-18. u_3 - Gust Probability Density Distribution, Altitude Band #6

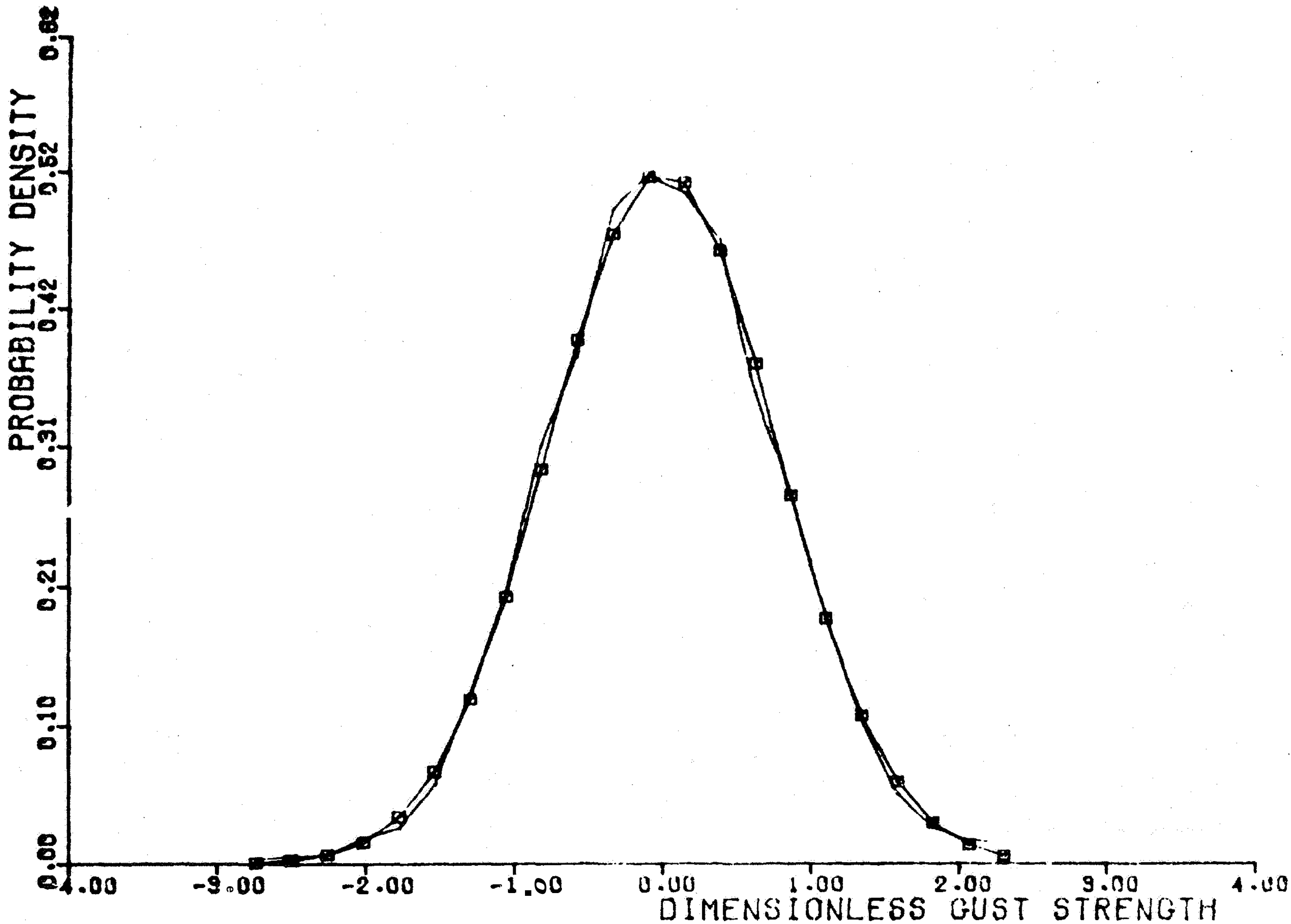

Figure B-19. $\partial u_2/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Band #1

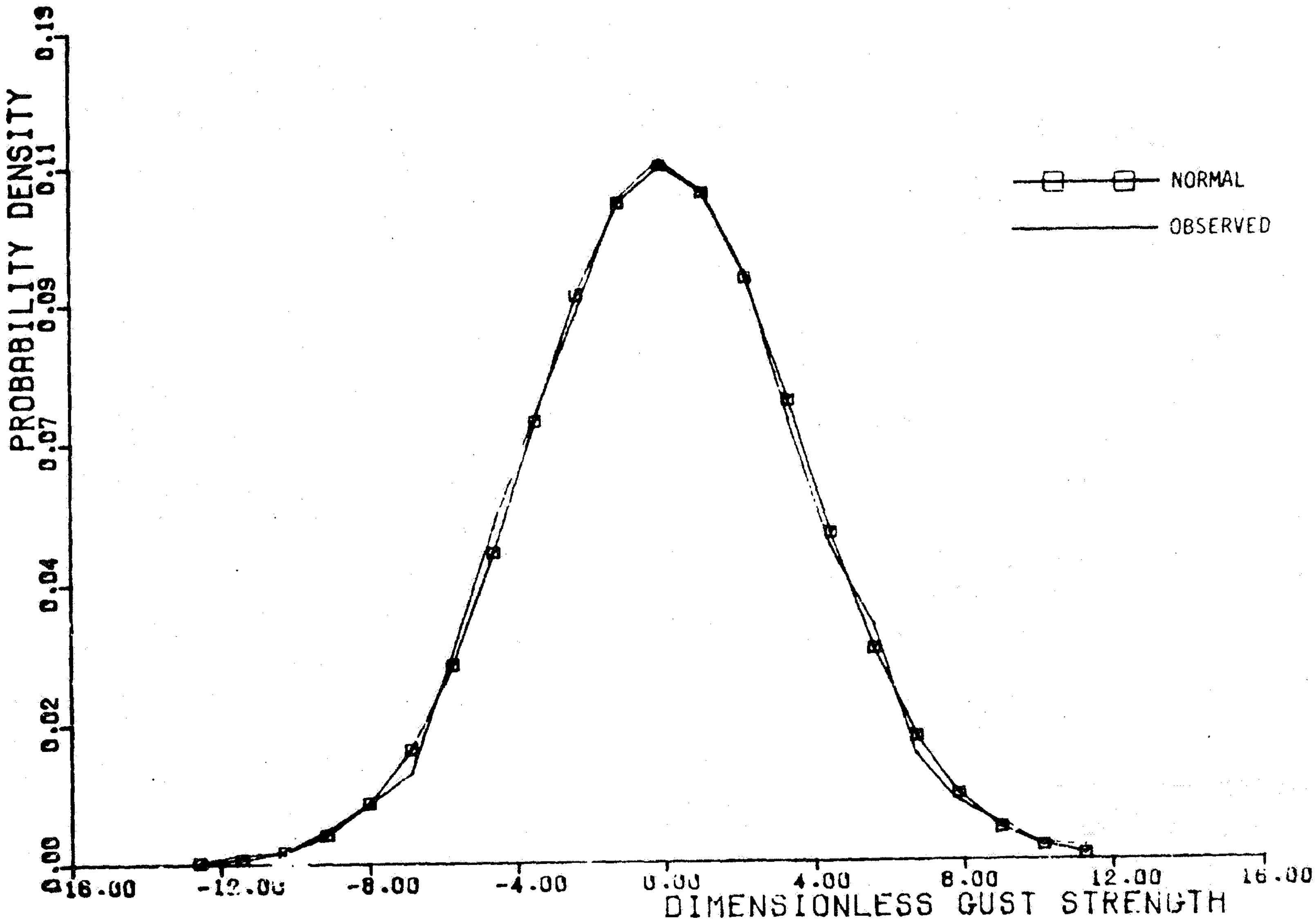

Figure B-20 $\partial u_2/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Band #2

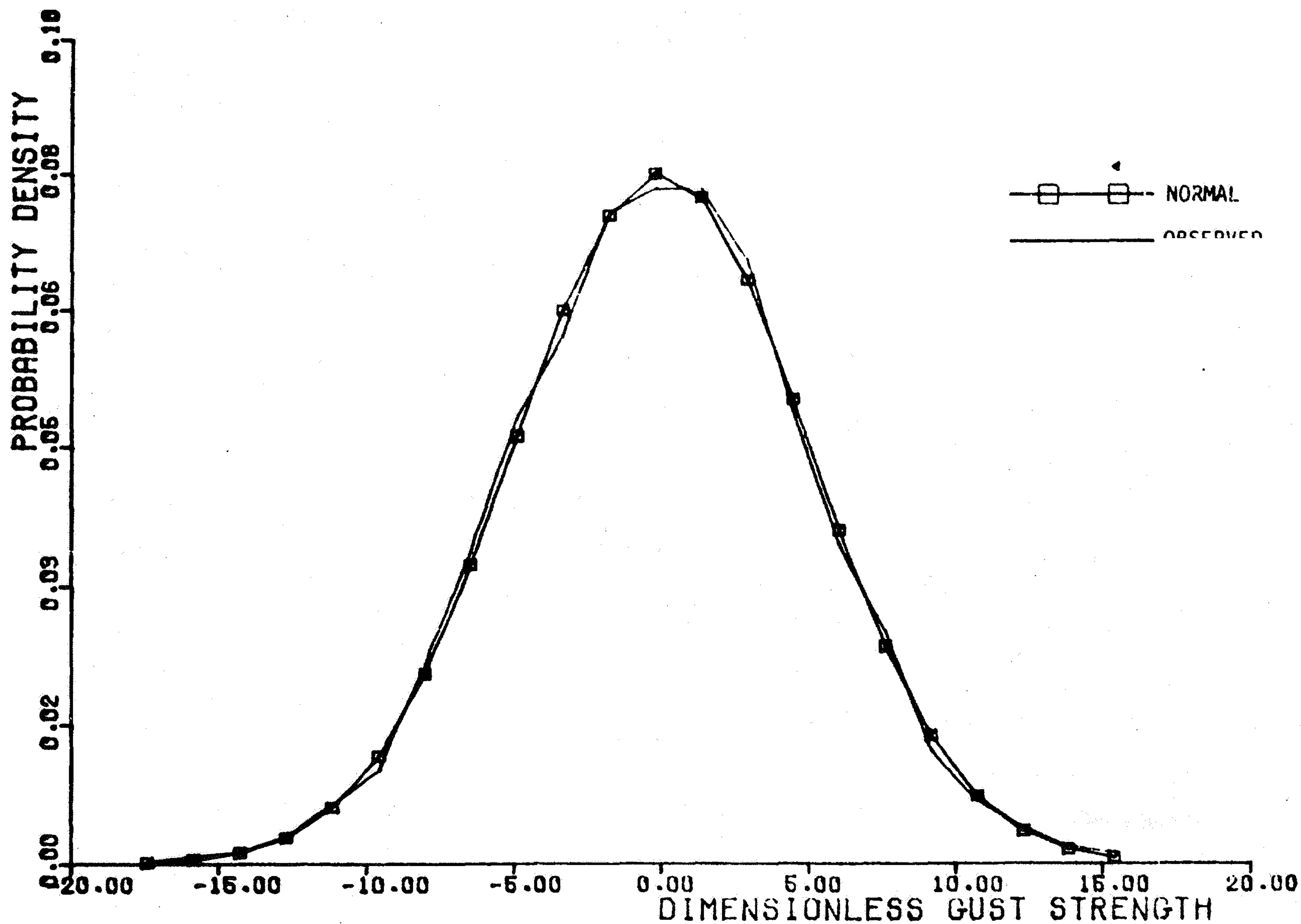

Figure B-21. $\partial u_2/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Band #3

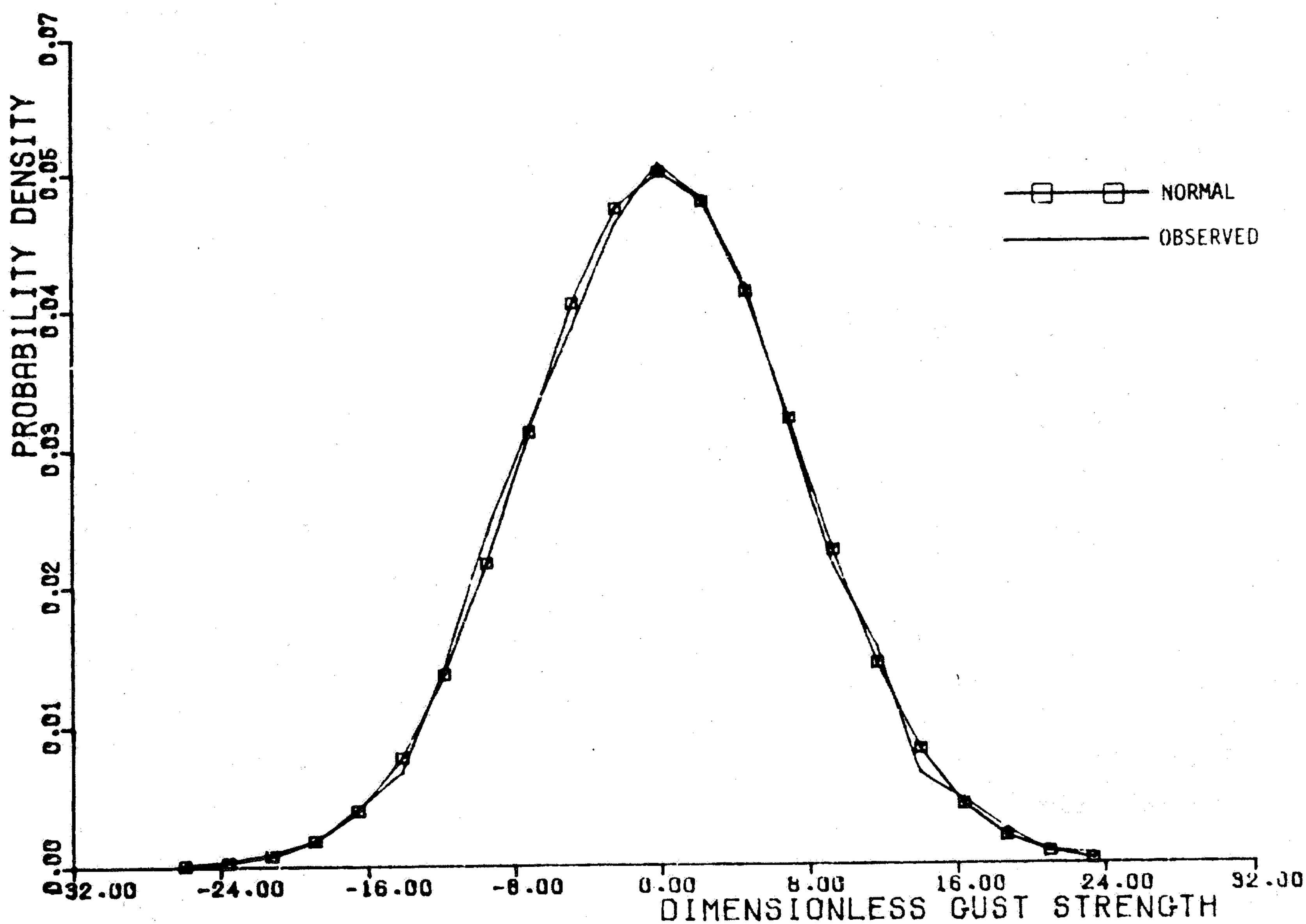

Figure B-22. $\partial u_2/\partial x_1$ - Gust Gradient Probability Density Distribution Altitude Band #4

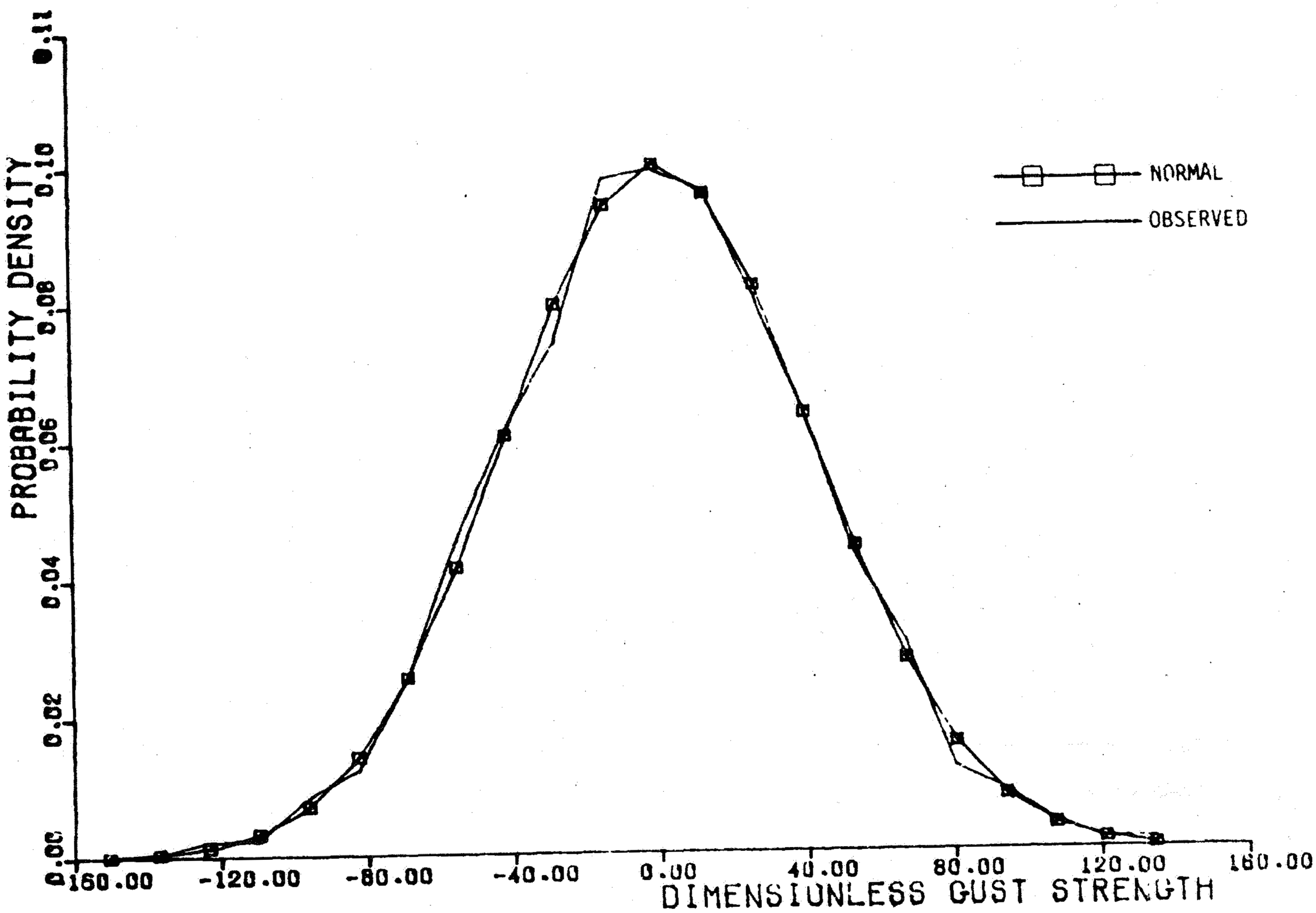

Figure 3-23 $\partial u_2/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Bard #5

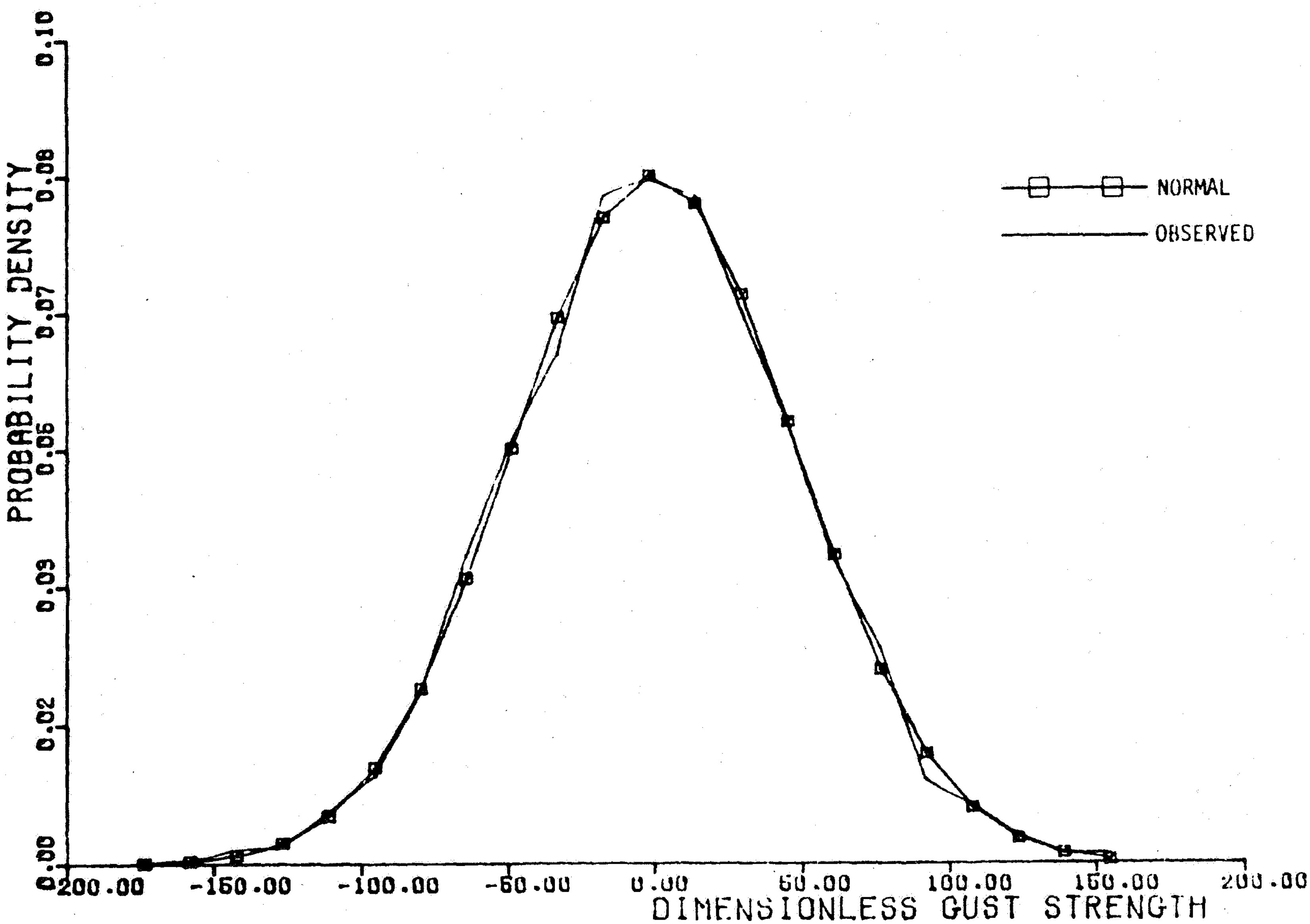

Figure B-24. $\partial u_2/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Band #6

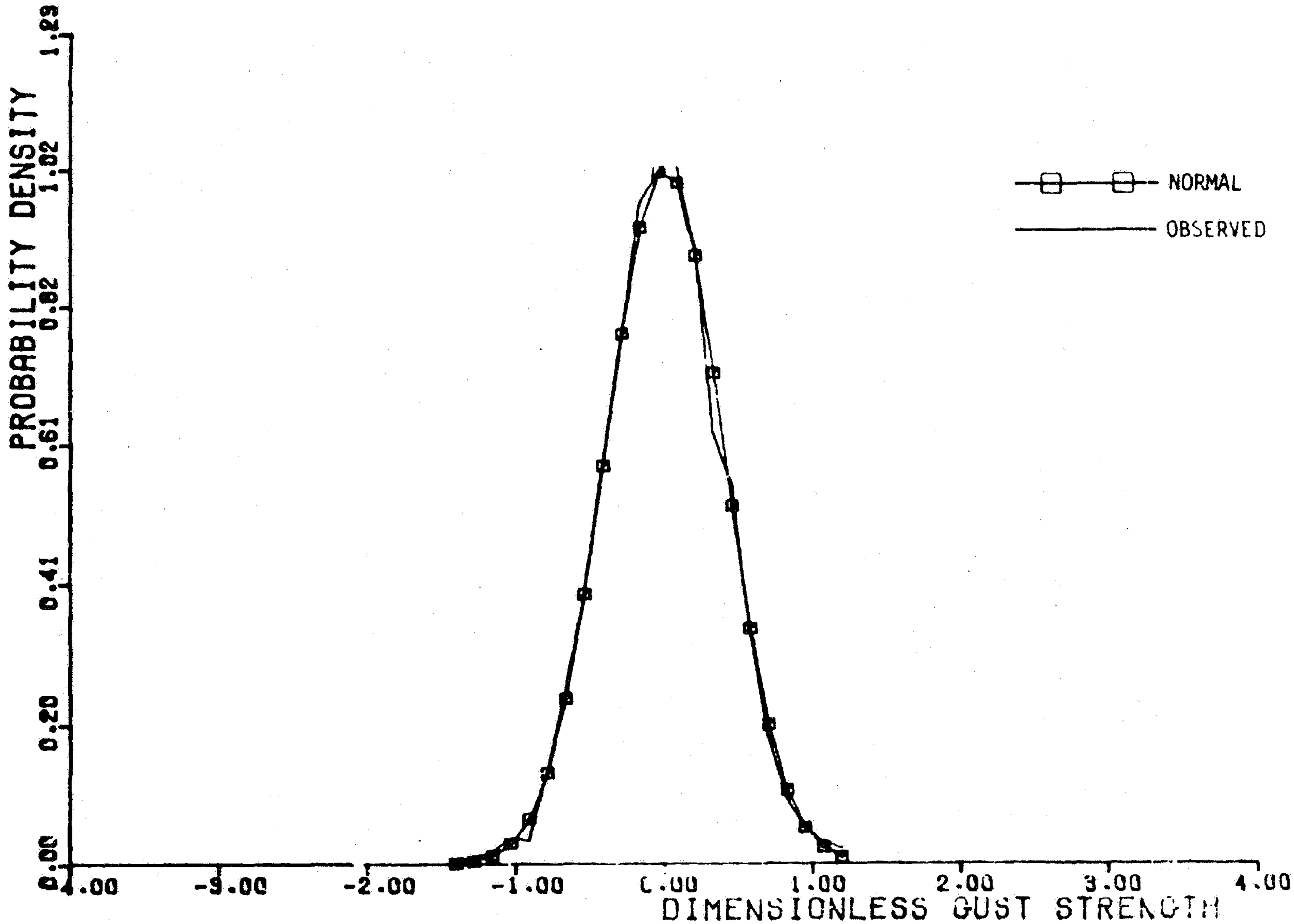

Figure B-25. $\partial u_3/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Band #1

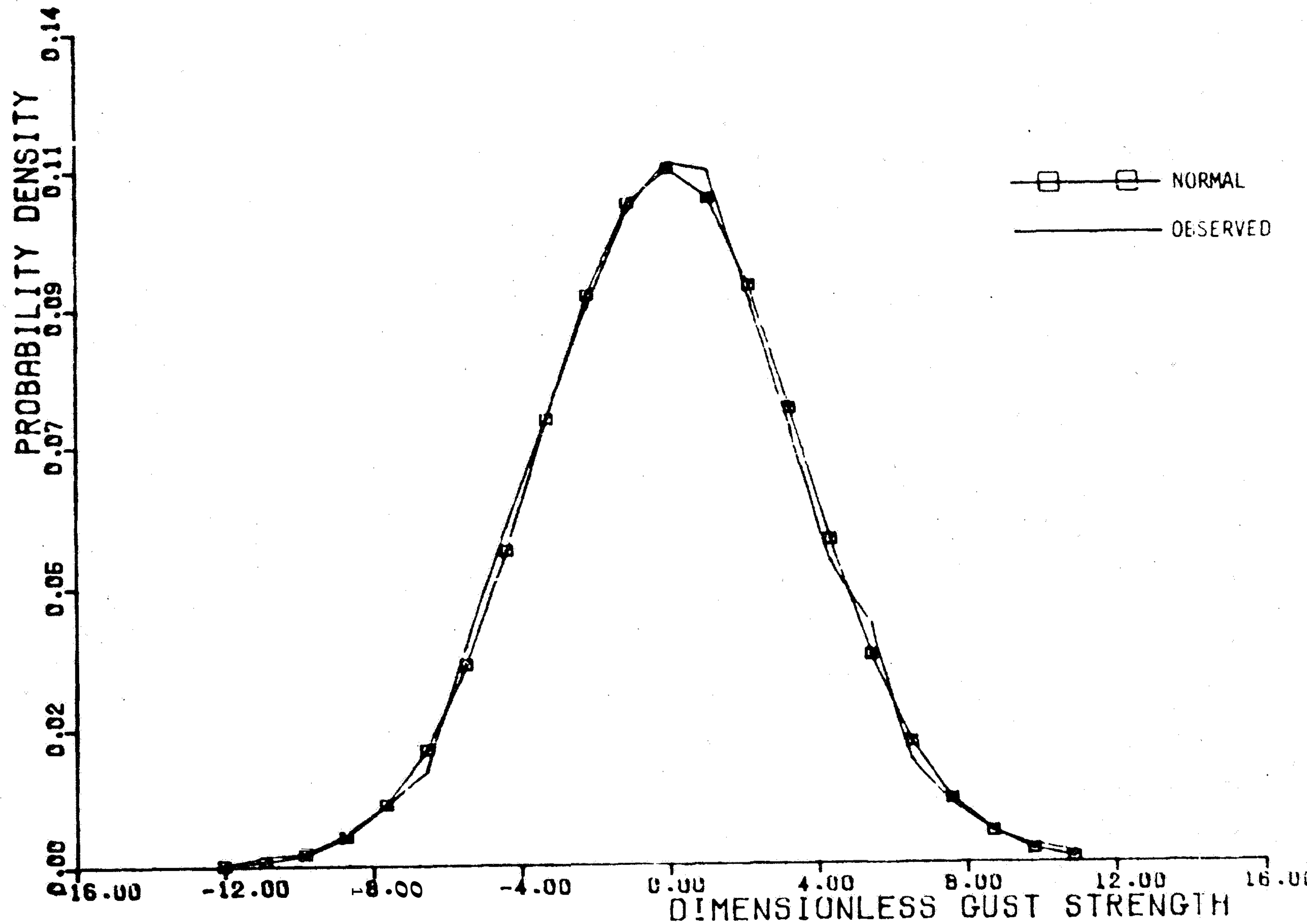

Figure . $\partial w_3/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Band #2

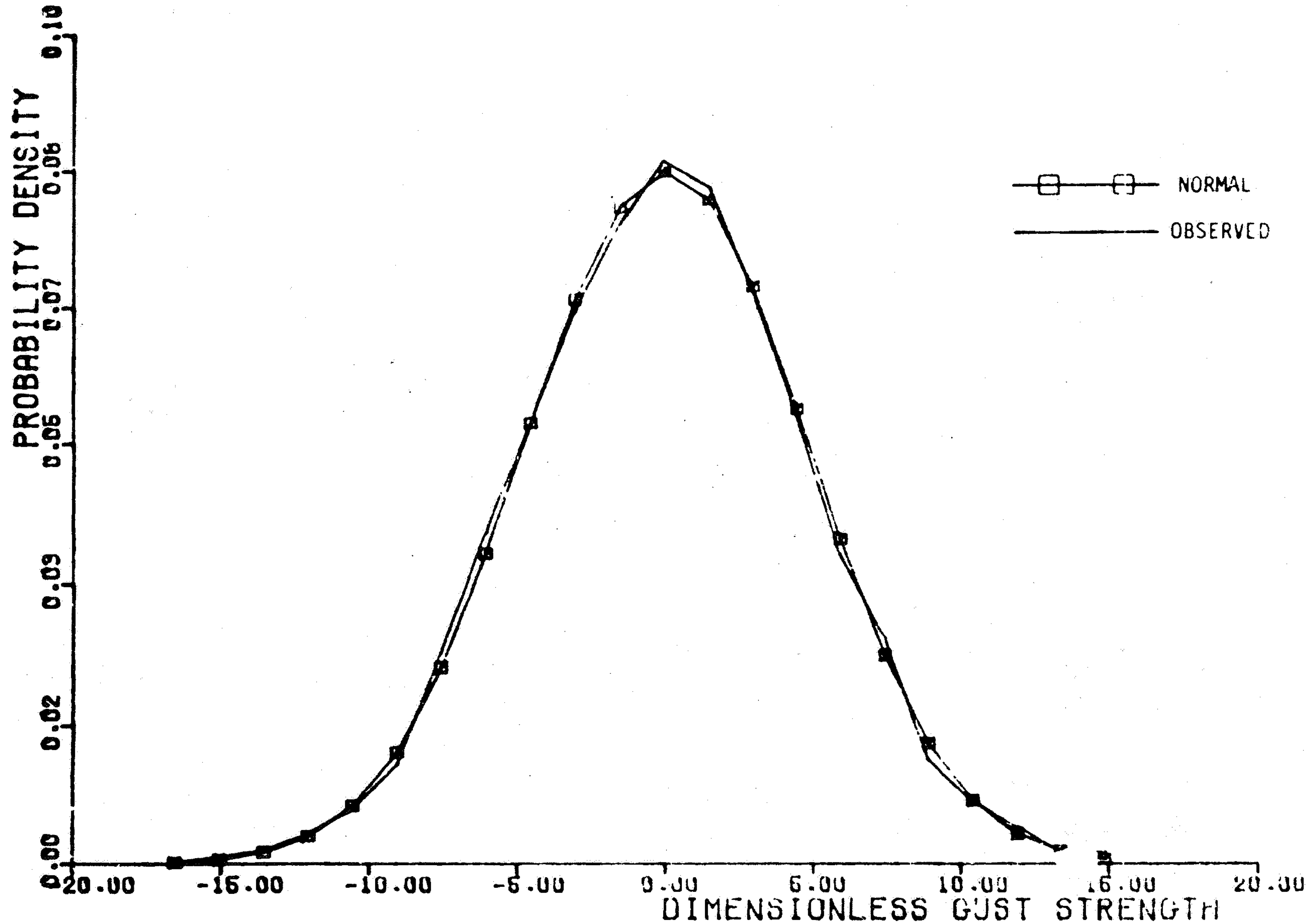

Figure B-27. $\partial u_3/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Band #3

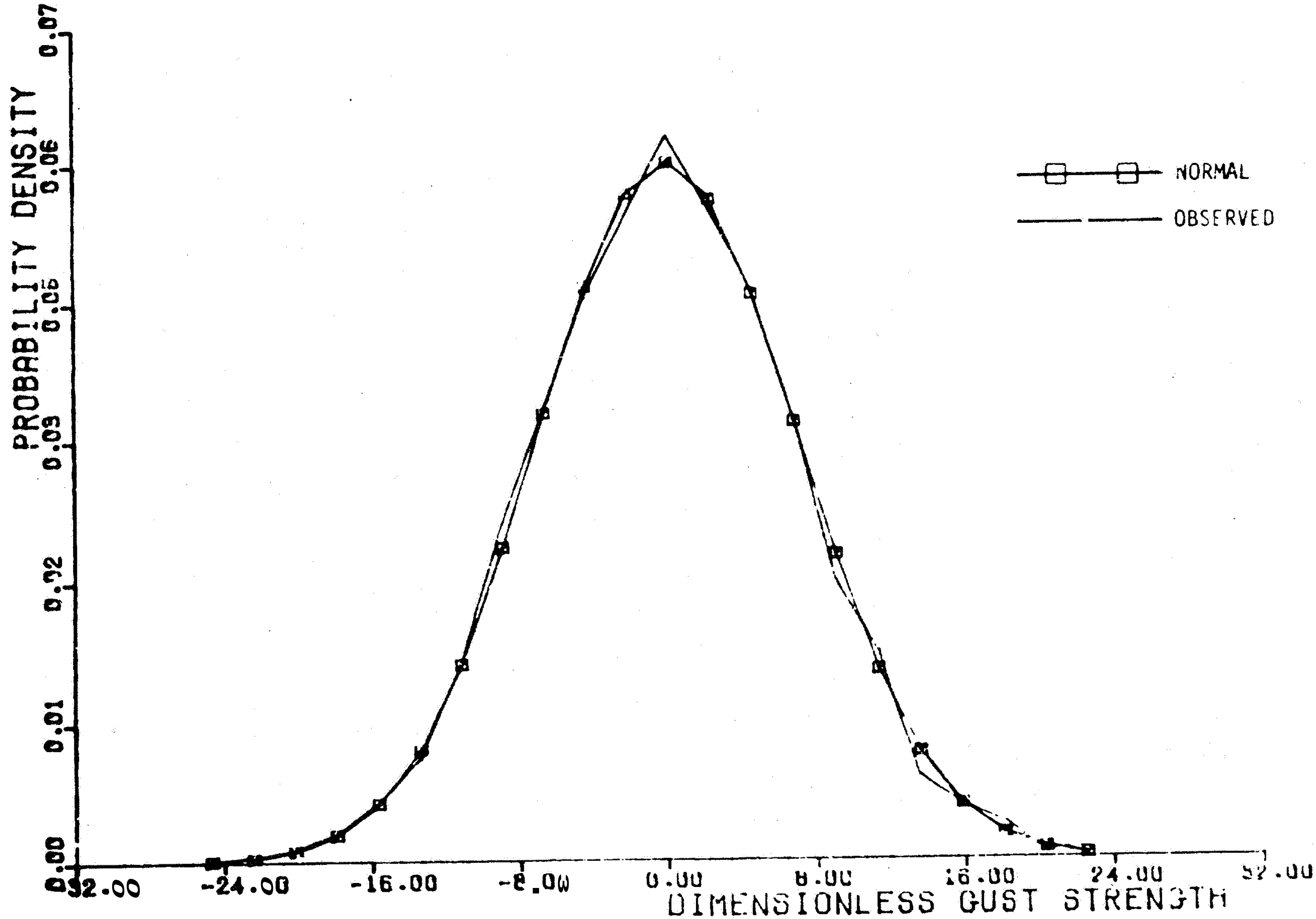

Figure B-28. $\partial u_3/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Band #4

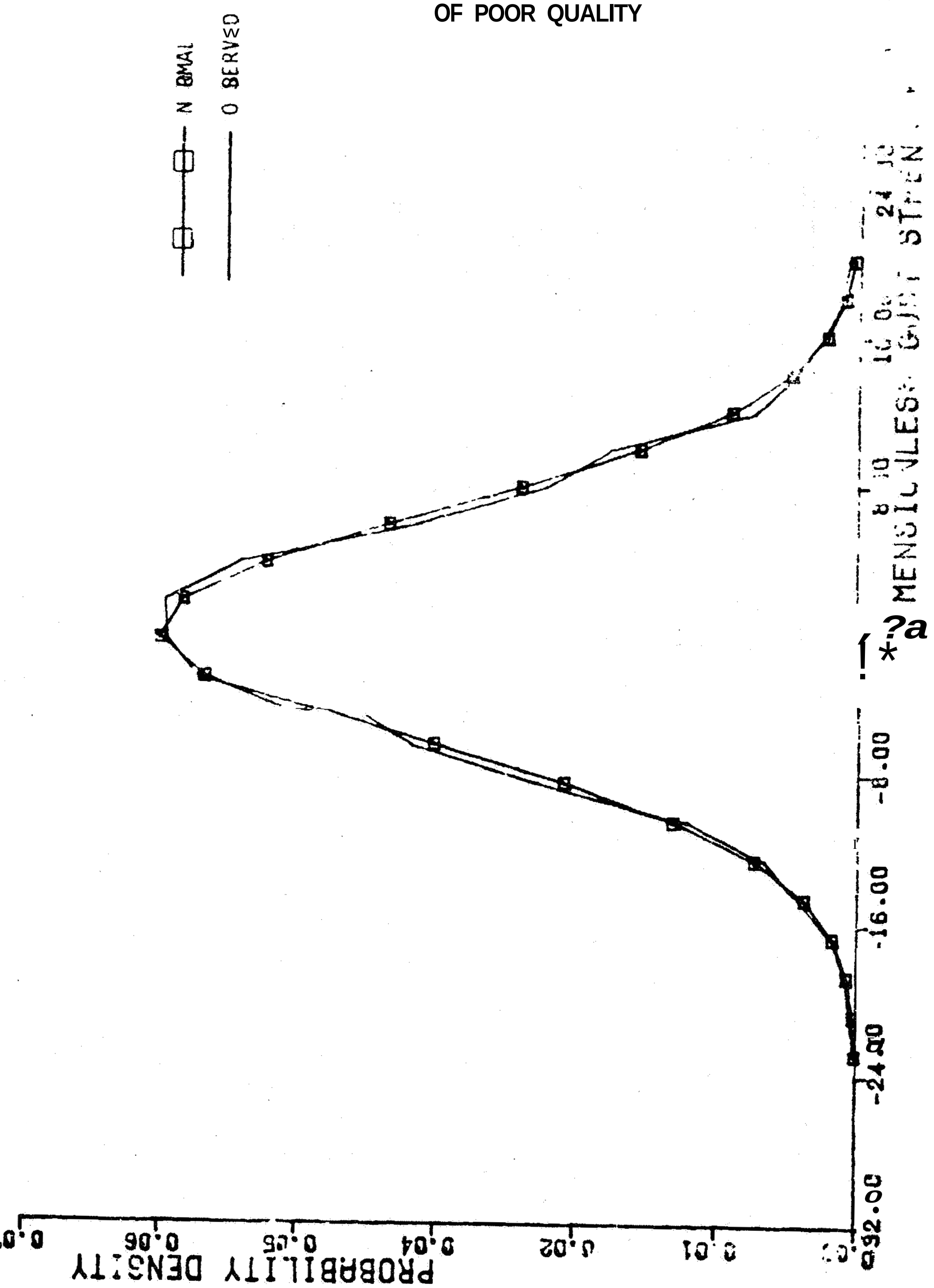

Figure 8-29. $\partial u_1/\partial x_1$ - Gust Gradient Probability Density Distribution

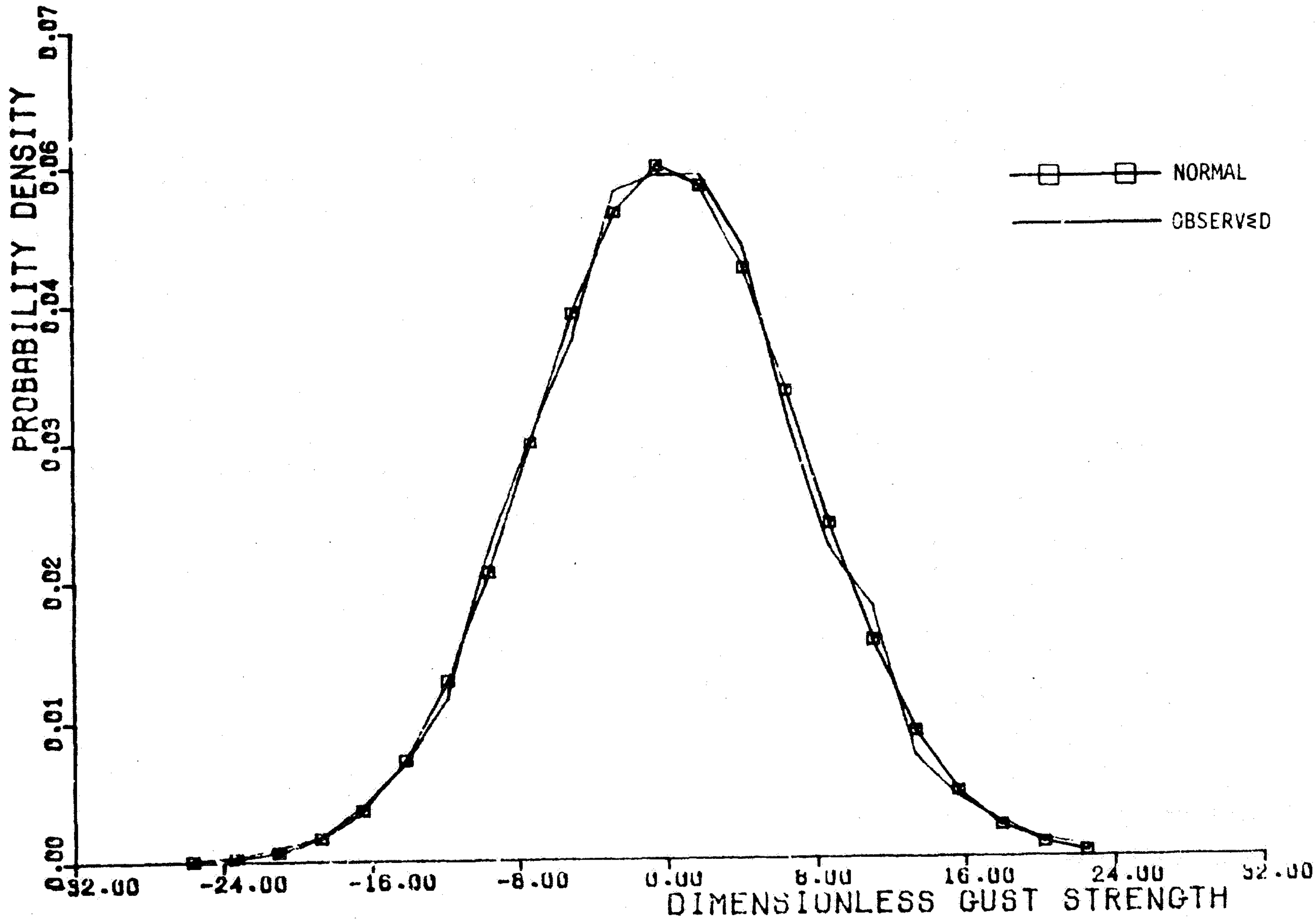

Figure B-30. $\partial u_3/\partial x_1$ - Gust Gradient Probability Density Distribution, Altitude Band #6

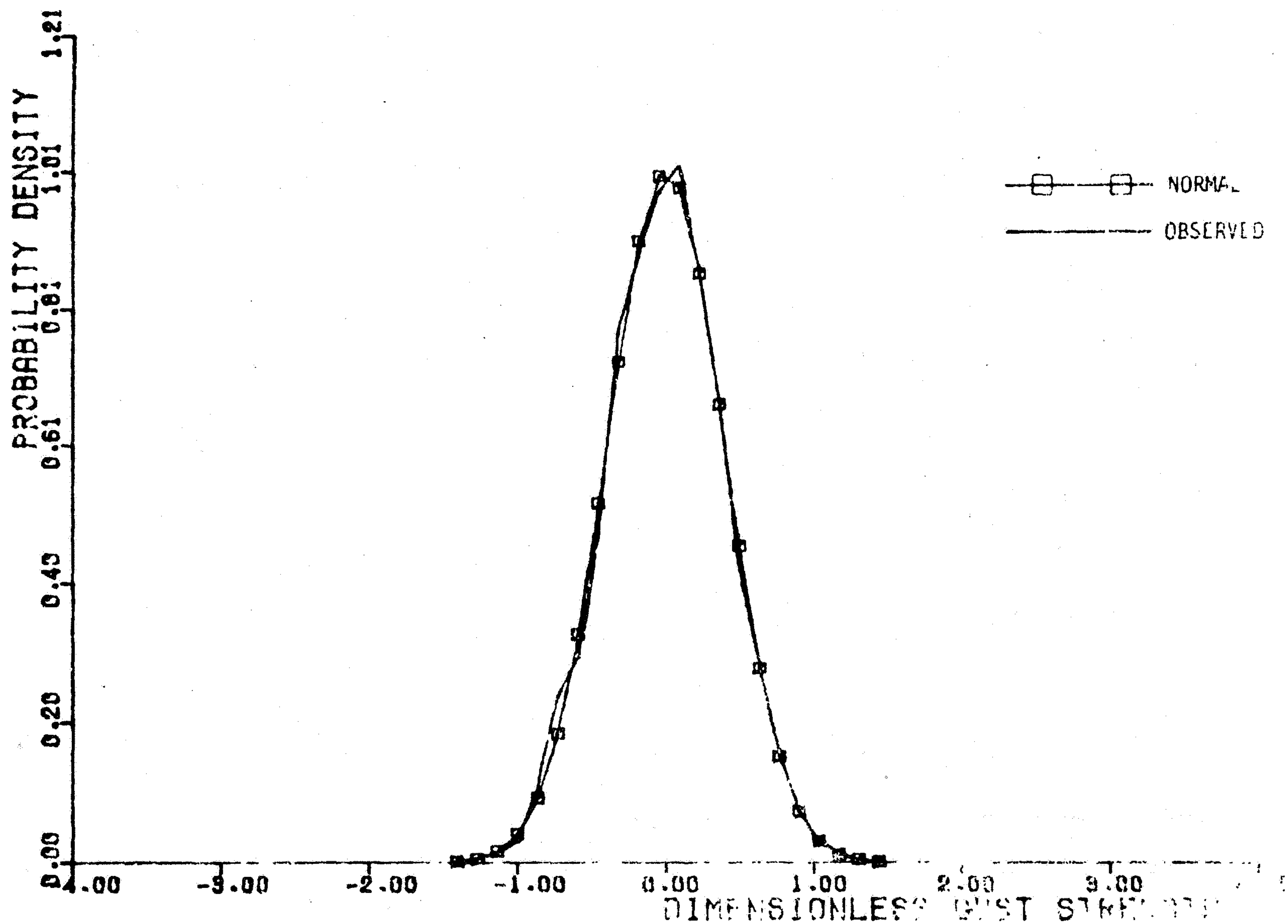

Figure B-31. $\partial u_3/\partial x_2$ Gust Gradient Probability Density Distrib[illegible] Altitu[illegible]

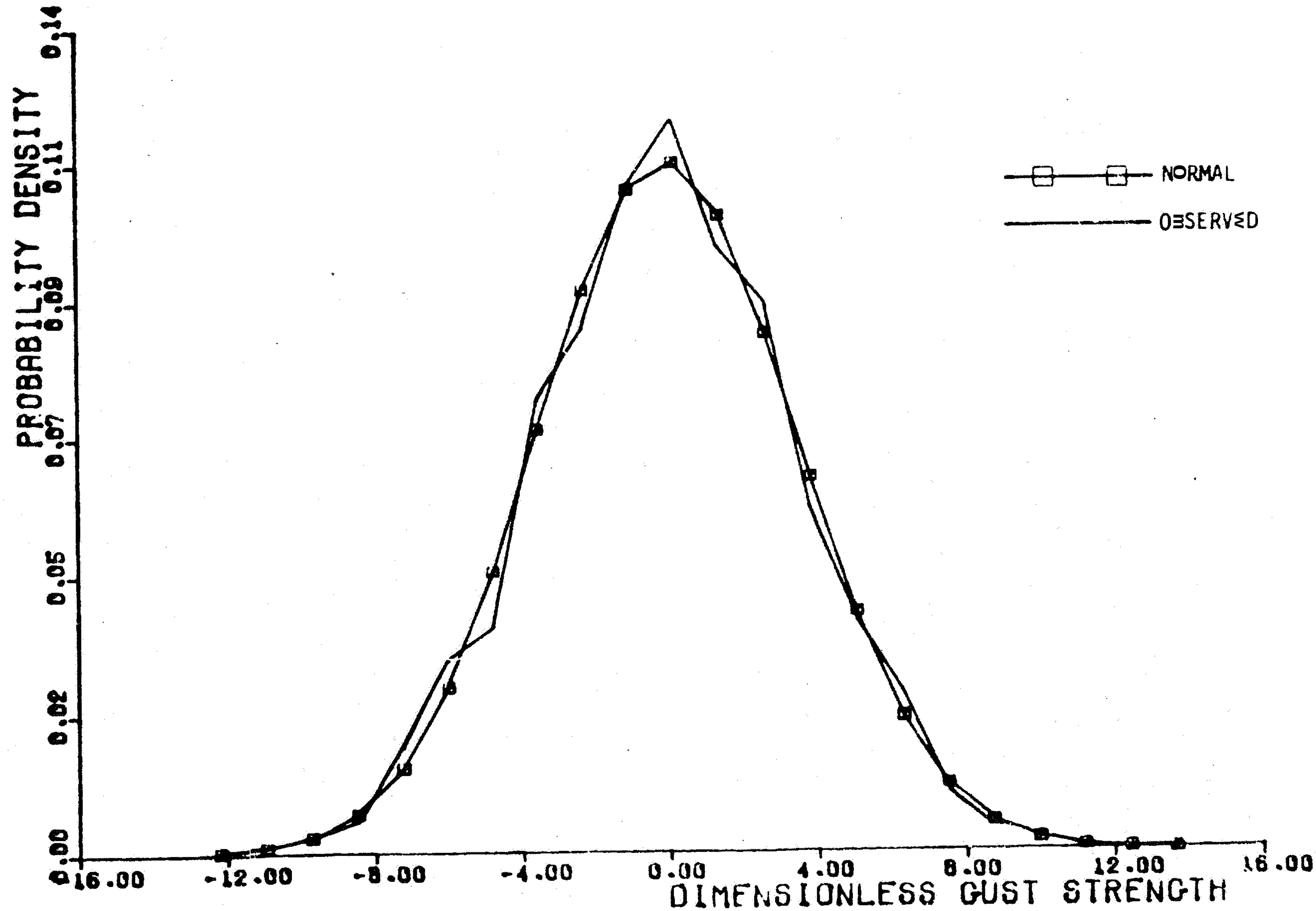

Figure B-32. $\partial w_3/\partial x_2$ - Gust Gradient Probability Density Distribution, Altitude Band #2

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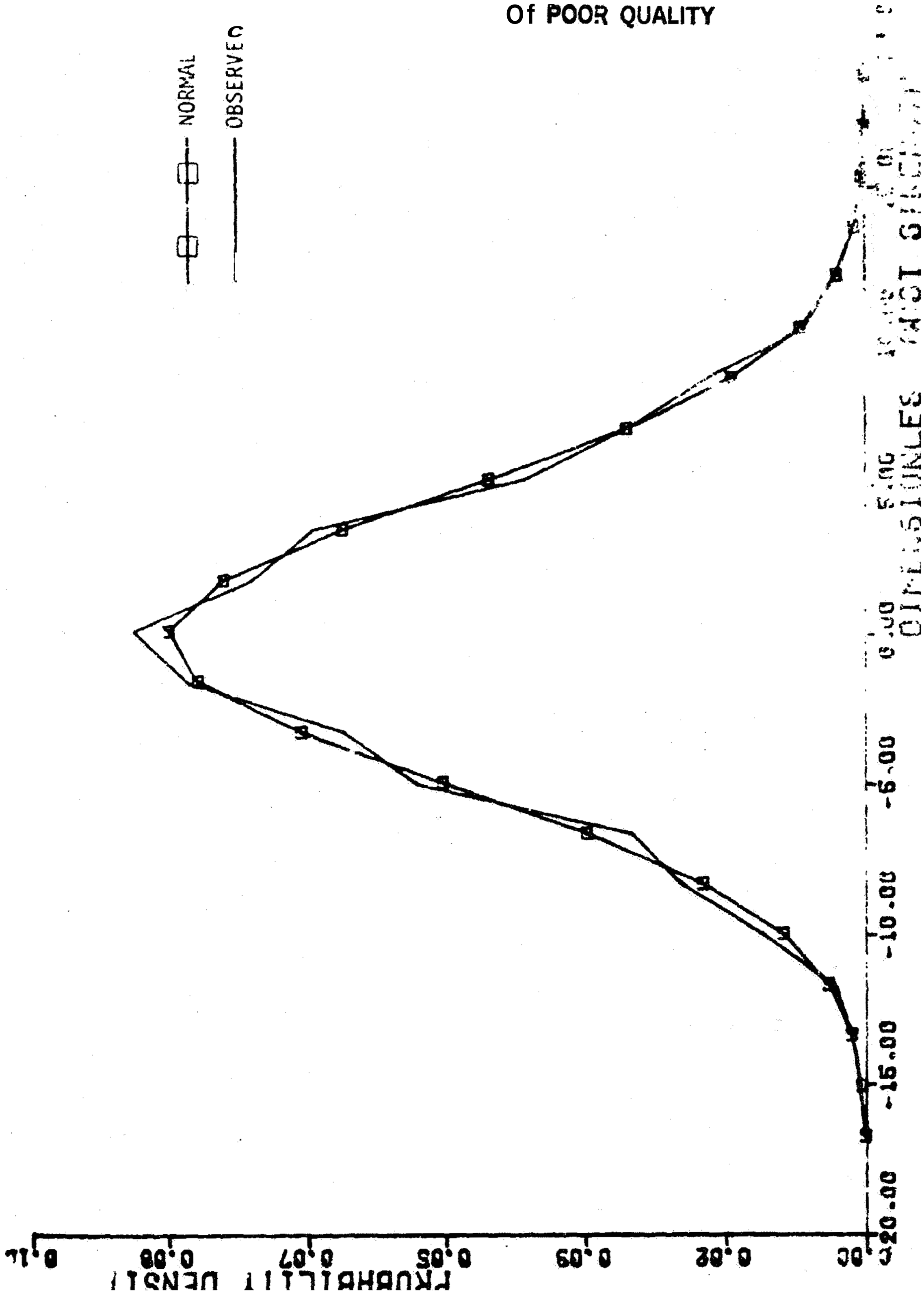

Figure B-33. $\partial u_3/\partial x_2$ - Gust Gradient Probability De[illegible] Distribut[illegible] A[illegible]tude R[illegible]

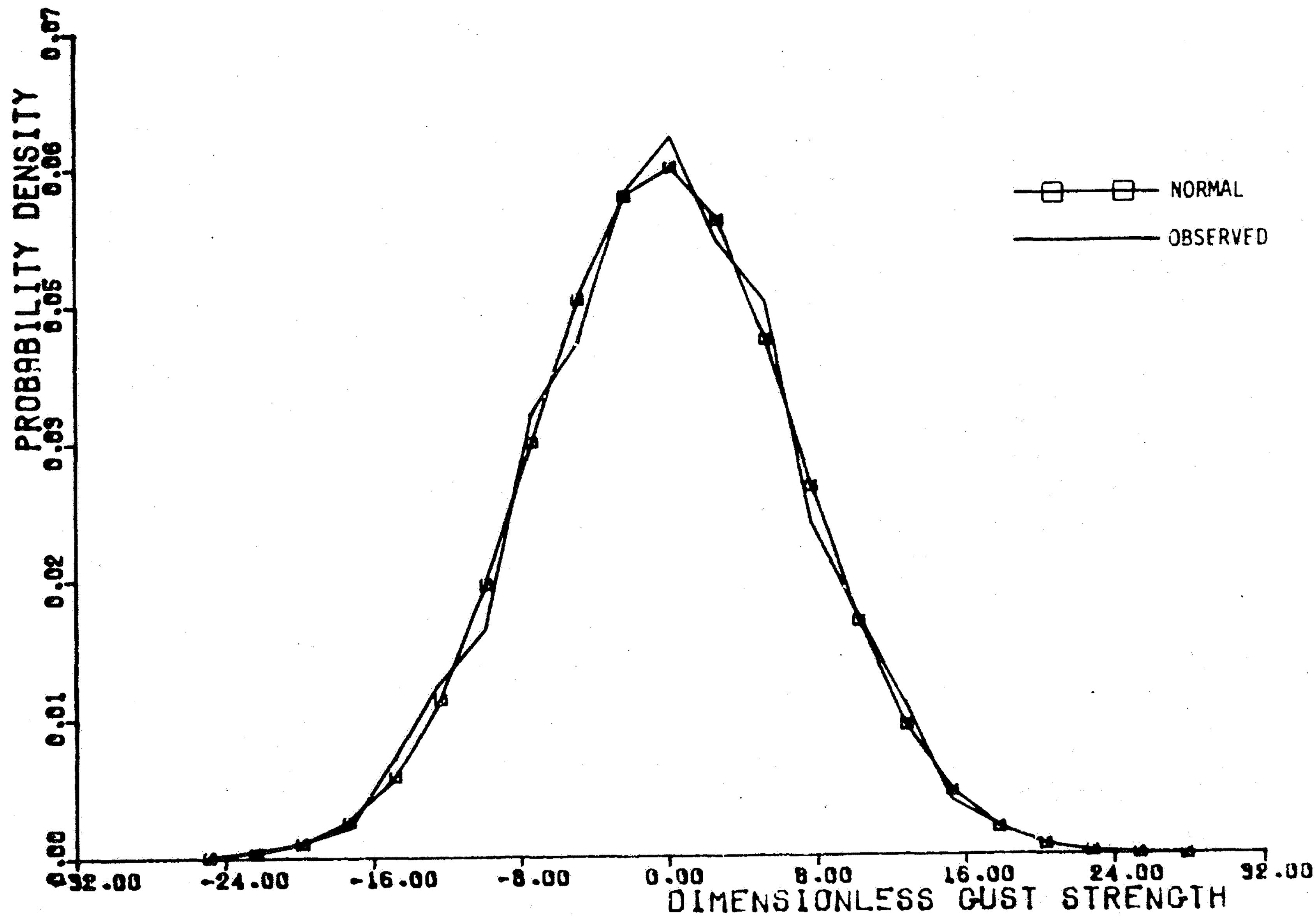

Figure B-34. $\partial u_3/\partial x_2$ - Gust Gradient Probability Density Distribution, Altitude Band #4

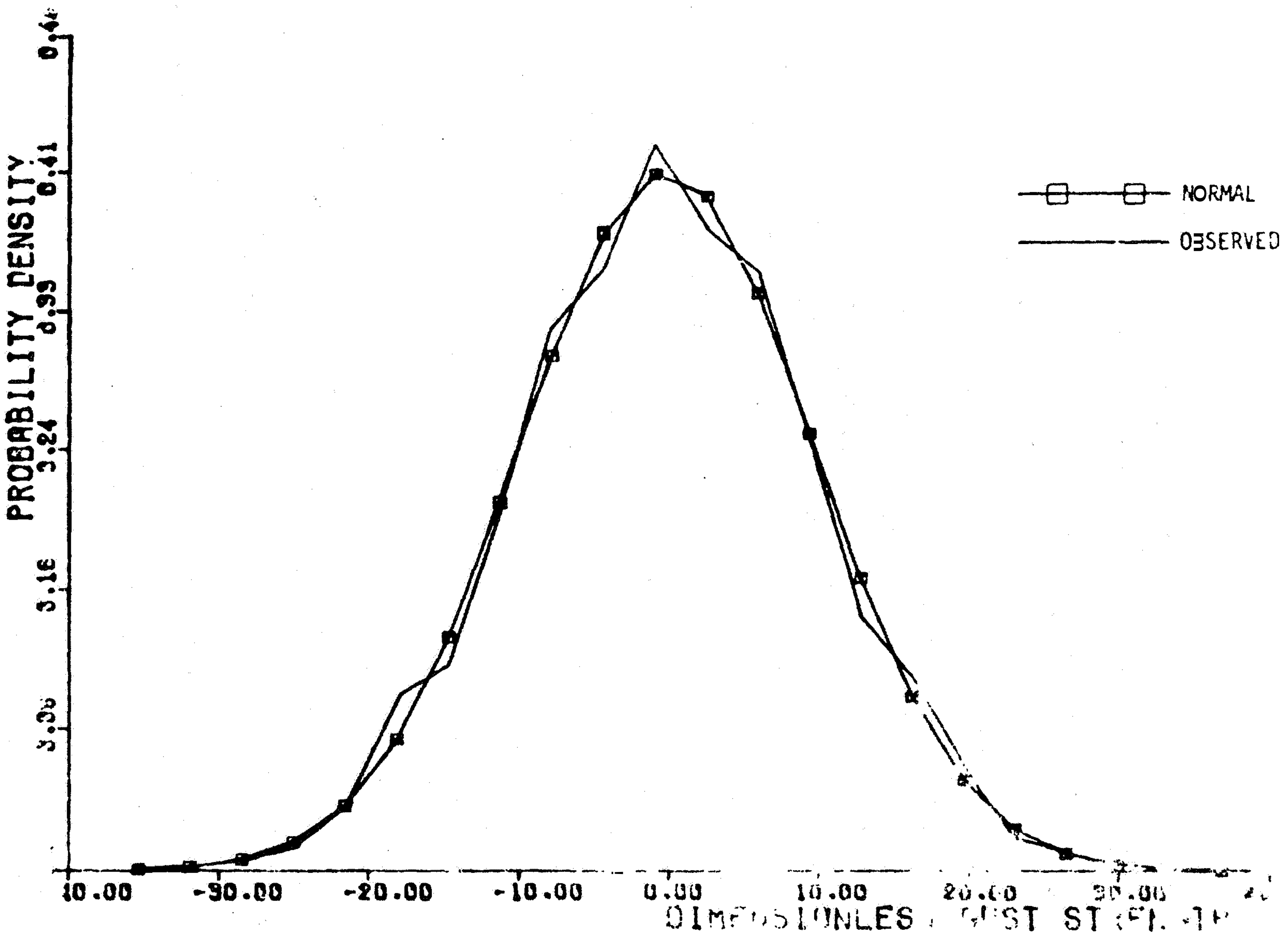

Figure B-35. $\partial u_3/\partial x_2$ - Gust Gradient Probability Density Distribution [illegible]titude Ba[illegible]

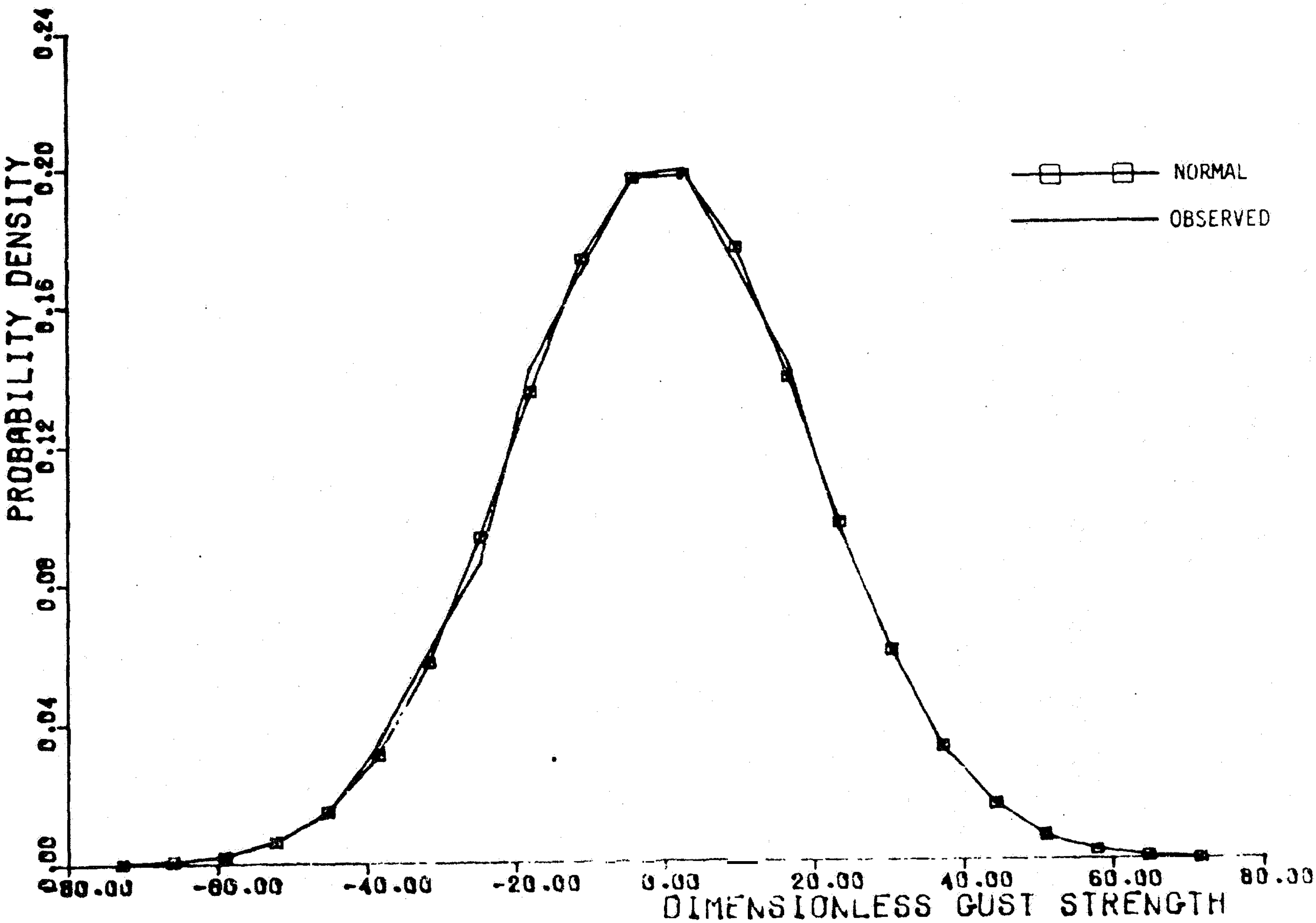

Figure B-36. $\partial u_3/\partial x_2$ - Gust Gradient Probability Density Distribution, Altitude Band #6

APPENDIX C

EXAMPLE USE OF SSTT

The example which follows consists of two parts. In the first part, covered in subsection C.l, sample records from two tapes are presented and explained. In the second part, described in subsection C.2, the dimensionlees time series corresponding to the same records are converted to *dimensional* form.

C.I EXAMPLE RECORDS FROM SSTT-1 AND SSTT-4

In order to provide the user with a clear picture of the manner in which the data are organized on each tape the first 40 records actually stored on SSTT-1 and SSTT-4 are presented in Tables C-1 and C-2 respectively. The first record on each tape contains a 36-character alphanumeric descriptor. The second record contains the tine series identification number (1-6), the number of points in the time series, and the dimensionless generation time step site for each altitude band. The format for this record is "2I10,4(1X,E14.7)". Following these two records, the time series is stored in 6-word records with the format "6(1X,E14.7)". The order of storage in each record is from lowest to highest altitude band. Thus the first word in each record corresponds to band #1, the second to band #2, etc.

C.2 EXAMPLE CONVERSION FROM DIMENSIONLESS TO DIMENSIONAL TIME SERIES

c.2.1 Conversion of Gust Time Series, $u_1(t_n)$

As an example, the Space Shuttle is assumed to be at the following point in its descent trajectory:

altitude (Z_n) - 9000 m

velocity (V_n) - 270 m/sec

This point in the trajectory for simplicity is assumed to correspond to the *first* term (N=1) in the dimensionless time series as recorded in the *third* record of SSTT-1 presented in Table C-1. The conversion steps proceed as follows:

TABLE C-1. SSTT-1 EXAMPLE RECORDS

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RECORD #								
1	TURBULENT GUSTS GENERATED 05 16-81							
2	1	8500	.6519721E+00	.1443614E+00	.9431944E-01	.5303712E-01	.4265570E-02	.3510551E 02
3	-.6739144E+00	-.6185604E+00	-.5238217E+00	-.4110193E+00	-.5433123E+00	-.5655433E+00		
4	-.3571564E+00	-.4152705E+00	-.3369752E+00	.5120?2E+00	-.4406694E+00	-.463..57E+00		
5	-.1160903E+01	-.8605521E+00	-.7227465E+00	-.5577414E+00	-.5745736E+00	.1094228E+00		
6	-.2920414E+00	-.2091856E+00	-.1374379E+00	-.6365418E-01	-.3127302E+00	-.7300705E+00		
7	.2238827E+00	.2663171E+00	.2903881E+00	.2893733E+00	-.1513643E+00	-.1772641E+00		
8	.1145988E+00	.3505585E+00	.3773271E+00	.3669710E+00	-.7817809E-01	-.1043356E+00		
9	.7124773E+00	.8744198E+00	.8423297E+00	.7561480E+00	.4604382E-01	.6153656E-02		
10	.1490304E+01	.1468735E+01	.1368192E+01	.1194453E+01	.2026800E+00	.1500030E+00		
11	.1714107E+01	.1617451E+01	.1500315E+01	.1308493E+01	.2491474E+00	.1936700E+00		
12	.5991361E+00	.8226740E+00	.8102150E+00	.7461791E+00	.1358770E-01	-.3171739E-01		
13	-.2899164E+00	.1910813E+00	.2586429E+00	.2361214E+00	-.1907722E+00	-.2296870E+00		
14	.1168710E+00	.2896449E+00	.3396018E+00	.3651233E+00	-.7561249E-01	-.1059414E+00		
15	-.7888348E+00	-.3457098E+00	-.2153032E+00	-.8881503E-01	-.3535733E+00	-.3862761E+00		
16	-.1605417E+00	.3169205E-01	.1091817E+00	.1776028E+00	-.2085572E+00	-.2420689E+00		
17	.2417949E-01	.1693297E+00	.2254679E+00	.2737577E+00	-.1108891E+00	-.1428994E+00		
18	.1822122E-01	.1940306E+00	.2460706E+00	.2904247E+00	-.1386707E+00	-.1746745E+00		
19	.5166534E+00	.5327635E+00	.5373664E+00	.5302659E+00	.3483037E-01	.6193630E-05		
20	.6393229E+00	.7205431E+00	.6933707E+00	.6631919E+00	.1047048E+00	.6832627E-01		
21	.2454413E+00	.2784138E+00	.3143568E+00	.3474014E+00	-.4041896E-01	-.7190785E-01		
22	-.3614624E+00	-.1945672E+00	-.9786105E-01	.8651808E-02	-.1634485E+00	-.1855733E+00		
23	-.1156895E+01	-.7441703E+00	-.5742023E+00	-.3819098E+00	-.3537109E+00	-.3716951E+00		
24	-.8509248E+00	-.5145035E+00	-.3713275E+00	-.2130673E+00	-.2404665E+00	-.2589253E+00		
25	.3194910E+00	.3218631E+00	.3596431E+00	.3898004E+00	.5710532E-01	.3069272E-01		
26	.5044527E+00	.5340239E+00	.5495572E+00	.5482765E+00	.1074539E+00	.7414198E-01		
27	.2371427E+00	.4292948E+00	.4655139E+00	.4798326E+00	.1242532E+00	.9544277E-01		
28	.1954756E+00	.4544126E+00	.4934292E+00	.5031519E+00	.2058206E+00	.1814379E+00		
29	.3930210E+00	.5730420E+00	.6035095E+00	.5925360E+00	.3007517E+00	.2801964E+00		
30	-.1609266E+00	.3782437E+00	.4380605E+00	.4560364E+00	.2270506E+00	.2046421E+00		
31	.5874951E+00	.8889327E+00	.8830619E+00	.8190024E+00	.4773401E+00	.4584527E+00		
32	.5290890E+00	.9371415E+00	.9245096E+00	.8499167E+00	.5119239E+00	.4915624E+00		
33	.1323519E+01	.1492482E+01	.1401994E+01	.1235476E+01	.7234266E+00	.7016613E+00		
34	.1142977E+01	.1381556E+01	.1296074E+01	.1140206E+01	.7232891E+00	.7057141E+00		
35	.9505661E+00	.1201720E+01	.1126836E+01	.9903720E+00	.6689756E+00	.6548799E+00		
36	.1357352E+01	.1337407E+01	.1225893E+01	.1058661E+01	.7200285E+00	.7090716E+00		
37	.4525653E+00	.5862546E+00	.5500441E+00	.4305623E+00	.4544587E+00	.4521182E+00		
38	-.1365918E+00	.4242453E-02	.1785966E-01	.4072478E-01	.2984878E+00	.2991245E+00		
39	-.6954330E-01	-.1564458E+00	-.1491442E+00	-.1083869E+00	.2994357E+00	.3203633E+00		
40	.7606563E-01	-.2782416E+00	-.2799207E+00	-.2286164E+00	.2859467E+00	.3159975E+00		

This column is not stored as part of the records but has been provided for convenience.

TABLE C-2 SSFT-4 EXAMPLE RECORDS

RECORD #								
1	TURBULENT GUSTS GENERATED 05-16-81							
2	4	6500	.1021490E+01	.1483259E+00	.9431948E-01	.5303717E 01	.4265570E-02	.[illegible]E-02
3	-.2800310E+00	-.2167305E+01	-.3028911E+01	.4476954E+01	-.2505049E+02	-.2381014E+02		
4	.7918676E+00	.2095055E+01	.2761363E+01	.4036425E+01	.2513683E+02	.2949057E+02		
5	-.1305635E+01	-.6613907E+01	-.3052605E+01	-.1329581E+02	-.7472113E+02	-.8607602E+02		
6	.2625560E+00	.2926297E+00	.3796731E+00	.5937763E+00	.5263534E+01	.6405128E+01		
7	.3770130E+00	.1535942E+01	.2137045E+01	.3323266E+01	.1354158E+02	.2130322E+02		
8	-.4534109E+00	-.1571739E+01	-.2021604E+01	-.2315561E+01	-.1539248E+02	.1787801E+02		
9	-.4871162E-01	.8535987E+00	.1334508E+01	.2123356E+01	.1237363E+02	.1395720E+02		
10	.5065041E+00	.4141794E+01	.5851079E+01	.3798355E+01	.4371353E+02	.5548253E+02		
11	.1021620E+01	.6300869E+01	.376[illegible]57E+01	.1311027E+02	.7307964E+02	.8359483E+02		
12	-.1010926E+00	.4287173E+00	.743[illegible]500E+00	.1291014E+01	.8202503E+01	.924[illegible]743E+01		
13	-.8774065E+00	-.3706079E+01	-.4934185E+01	-.7093613E+01	-.3963605E+02	-.453[illegible]765E+02		
14	.9031401E+00	.3043047E+01	.4178502E+01	.6273796E+01	.3854331E+02	.449[illegible]71E+02		
15	-.1223793E+01	-.5876492E+01	-.7972481E+01	-.1153200E+02	-.6509712E+02	-.7514372E+02		
16	.3483040E+00	.7117826E+00	.9681619E+00	.1526429E+01	.1122922E+02	.1329705E+02		
17	.5329763E-01	.4622062E-01	.7104798E-01	.2055976E+00	.1740848E+01	.1922124E+01		
18	-.2911199E+00	-.1109578E+01	-.1484447E+01	-.2082684E+01	-.1054735E+02	-.1221310E+02		
19	.1418803E+00	.1294358E+01	.1792251E+01	.2730937E+01	.1541635E+02	.1745351E+02		
20	.7293521E+00	.3919365E+01	.5352765E+01	.7957416E+01	.4520233E+02	.5184507E+02		
21	-.7530332E-02	.3036390E+00	.4084185E+00	.6819143E+00	.3735345E+01	.4026082E+01		
22	.1032257E+00	-.4332552E+00	-.6376252E+00	-.8722025E+00	-.2817612E+01	-.2962626E+01		
23	-.8694503E+00	-.5229354E+01	-.7182525E+01	-.1049506E+02	-.5675381E+02	-.6501245E+02		
24	-.6748942E+00	-.4010304E+01	-.5501787E+01	-.8013580E+01	-.4335094E+02	-.4969331E+02		
25	.6905962E+00	.2792221E+01	.3796583E+01	.5672916E+01	.3296595E+02	.3803719E+02		
26	.3170481E+00	.1816199E+01	.2519295E+01	.3825650E+01	.2146081E+02	.2448360E+02		
27	-.0572192E-01	-.9674685E-01	-.4716875E-01	.7221160E-01	.1374852E+01	.1524276E+01		
28	-.1550074E+00	-.4909621E+00	-.5570832E+00	-.6531018E+00	-.3406033E+01	-.4085945E+01		
29	.4237320E+00	.1649263E+01	.2376427E+01	.3675074E+01	.2270283E+02	.2636548E+02		
30	-.8641903E+00	-.3585265E+01	-.4783304E+01	-.6700100E+01	-.3790607E+02	-.4392886E+02		
31	.6230937E+00	.2750060E+01	.3942599E+01	.6020756E+01	.3618137E+02	.4194895E+02		
32	-.6309584E+00	-.1692734E+01	-.2048427E+01	-.2758896E+01	-.1656770E+02	-.1955580E+02		
33	.8010030E+00	.4678653E+01	.6637379E+01	.1000476E+02	.5688979E+02	.6539149E+02		
34	.8071946E-01	.1926617E+01	.2901640E+01	.4504762E+01	.2482636E+02	.2821566E+02		
35	-.3414602E+00	.1594237E+00	.4780954E+00	.9119906E+00	.4090480E+01	.4217690E+01		
36	.1024709E+01	.5671521E+01	.7915253E+01	.1178395E+02	.6644099E+02	.7636374E+02		
37	-.2353106E+00	-.1930107E+00	-.1353432E+00	-.1111245E+00	-.1492990E+01	-.2034244E+01		
38	-.3760014E+00	-.1590025E+01	-.2130227E+01	-.3126036E+01	-.1670670E+02	-.1910644E+02		
39	-.1180103E+00	-.4557762E+00	-.6732270E+00	-.1061913E+01	-.7150920E+01	-.8377735E+01		
40	.1110304E+01	.4195607E+01	.5555070E+01	.8011755E+01	.4554801E+02	.5281716E+02		

This column is not stored as part of the records but has been provided for convenience.

1. Establish Proper Value for Index, i - Based on Table 2-1, for u_1 gusts, $i=1$

2. Establish Altitude Band - Based on Table 2-1 with $Z_1 = 9000$ m, the proper altitude band would be #4.

3. Read Dimensionless Time Increment, T_1 - Based on the sixth word (corresponding to Altitude Band #4) in the second record in SSTT-1, as presented in Table C-1, the dimensionless time increment, T_1, would be .05308717.

4. Determine Integral Scale, L_1 - Based on Table 3-3, with $Z_1 = 9000$ m, the proper integral scale, L_1, would be 533 meters.

5. Compute Dimensional Time -

$$t^*_{11} = \sum_{n=1}^{1} \Delta t^*_{1n}$$

$$= aT_1 \sum_{n=1}^{i} L_{1n}/V_n$$

$$= (1.339)\cdot(.05308717)\cdot(533/270)$$

$$= .1403 \text{ sec}$$

6. Read Dimensionless Gust - Based on the *fourth* word (corresponding to Altitude Band #4) in the *third* record (corresponding to N=1) the dimensionless gust value is -.4110189.

7. Determine Standard Deviation in Direction of Gust - Based on Table 3-3 with $Z_1 = 9000$ m, the proper standard deviation, σ_1, would be 5.27 m/sec.

8. Compute Dimensional Gust -

$$u^*_1 = \sigma_1 u_1$$

$$= (5.27)(-.4110189)$$

$$= -2.17 \text{ m/sec}$$

C.7.2 Conversion of Gust Gradient Time Series, $\partial u_2/\partial u_1(t_n)$

In this example the same altitude and velocity are assumed for the Space Shuttle as in subsection C.2.1. This point in the trajectory, for simplicity, is assumed to correspond to the first term (N=1) in the dimensionless time series as recorded in the third record of SSTT-4 presented in Table C-2. The conversion steps proceed as follows:

1. Establish Proper Value for Index, i - Based on Table 2-2 for $\partial u_2/\partial x_1$ gust gradients, i = 2.
2. Establish Altitude Band - Based on Table 2-! with Z_1 = 9000 m, the proper altitude band would be Y4.
3. Read Dimensionless Time Increment, T_2 - Eased on the sixth word (corresponding to Altitude Band #4) in the second record in SSTT-1, as presented in Table C-2, the dimensionless time increment, T_2, would be .05308717.
4. Determine Integral Scale, L_2 - Based on Table 3-3, with Z_1 = 900 m, the proper integral scale, L_2, would be 533 meters.
5. Compute Dimensional Time -

$$t^*_{21} = \sum_{n=1} \Delta t^*_{2n}$$
$$= aT_2 \sum_{n=1}^{1} L_{2n}/V_n$$
$$= (1.339)\cdot(.05308717)\cdot(533/270)$$
$$= .1403 \text{ sec}$$

6. Read Dimensionless Gust Gradient - Based on the fourth word (corresponding to Altitude Band #4) in the third record (corresponding to N=1) the dimensionless gust gradient value is -4.476854.
7. Determine Standard Oeviation in Direction of Gust - Based on Table 3-3 with Z_1 = 9000 m, the proper standard deviation, σ_2, would be 5.27 m/sec.

8. Compute Dimensional Gust Gradient -

$$\frac{du_2^*}{\partial x_1^*} = \frac{\sigma_2}{L_E} \frac{\partial u_2}{\partial x_1}$$

$$= \left(\frac{5.27}{533}\right) \cdot (-4.476854)$$

$$= -.044 \text{ sec}^{-1}$$

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NASA CONTRACTOR REPORT CR-161890

ADVANCED SHUTTLE SIMULATION TURBULENCE TAPES (SSTT) USERS GUIDE

By Frank B. Tatom and S. Ray Smith

September 29, 1981

Cover: Part of title has been omitted; add words "Users Guide" to end of title.

Pages ii, 2-2, 3-7, 4-1, C-5: Replace with attached pages ii, 2-2, 3-7, 4-1, and C-5.

These changes are necessary to clarify and correct errors in instructions for use of the tapes.

TABLE OF CONTENTS

TABLE 2-1. SUMMARY OF TURBULENCE PARAMETERS IN DISCRETE ALTITUDE BANDS

BAND #	LOWER LIMIT (m)	UPPER LIMIT (m)	TURBULENCE LENGTH SCALE L_i (m)			TIME INTERVAL T_i (dimensionless)			MAXIMUM FREQUENCY Ω_{i1max} (dimensionless)		
			i = 1	i = 2	i = 3	i = 1	i = 2	i = 3	i = 1	i = 2	i = 3
1	0	30	43.4	2[illegible] 7	16 8	.6529	1.022	1.685	4.819	3.075	1.865
2	30	304 8	190	190	190	.1489	.1489	.1489	21.10	21.10	21.10
3	304 8	762	300	300	300	09432	09432	09432	33 310	33.310	33 310
4	762	10,000	533	533	533	05309	05309	05309	39 180	59.180	59.180
5	10,000	27,000	20,000	20,000	1,230	.004266	.004266	.06936	736.5	736.5	45.30
6	27,000	120,000	200,000	200,000	11,800	.003511	.003511	.05950	894.9	894.9	52.80

NOTE: $i = 1$ applies to u_1-gust

$i = 2$ applies to u_2-gust and $\partial u_2/\partial x_i$ gust gradients

$i = 3$ applies to u_3-gust and $\partial u_3/\partial x_1$ and $\partial u_3/\partial x_2$ gust gradients

TABLE 3-3. VARIATION OF STANDARD DEVIATION AND LENGTH SCALE WITH ALTITUDE (Continued)

ALTITUDE (m)	STANDARD DEVIATION OF TURBULENCE			INTEGRAL SCALES OF TURBULENCE		
	σ_1(m/sec)	σ_2(m/sec)	σ_3(m/sec)	L_1(m)	L_2(m)	L_3(m)
27000	7.00	7.00	4.22	20000	20000	1230
30000	8.23	8.23	4.66	23533	23533	1443
40000	12.82	12.82	6.09	36693	36693	2231
50000	18.08	18.08	7.51	51786	51786	3128
60000	23.94	23.94	8.90	68623	68623	4124
70000	30.36	30.36	10.28	87063	87063	5208
80000	37.29	37.29	11.65	106998	106998	6376
90000	44.70	44.70	13.01	128338	128338	7622
100000	52.58	52.58	14.35	151010	151010	8941
110000	60.89	60.89	15.69	174950	174950	10330
120000	69.62	69.62	17.02	200000	200000	11800

TABLE 3-4. VARIATION OF SHUTTLE SPEED WITH ALTITUDE [4]

ALTITUDE (m)	V (m/sec)
100	152
300	156
500	158
2000	170
4000	188
6000	200
8000	240
10000	300
20000	500
40000	1928
60000	4695
80000	7468
100000	7521
120000	7510

4. REFERENCES CITED

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3. Space Shuttle Program: Natural Environment Design Requirements. Appendix 10.10, Space Shuttle Flight and Ground Specification, Level II Program Definition and Requirements, *JSC 07700*, Vol. 10, Revision B. NASA-Lyndon B. Johnson Space Center, Houston, TX, August 18, 1975.

4. Fichtl, George H., "A Technique for Simulating Turbulence for Aerospace Vehicle Flight Sumulation Studies", *NASA TM 78141,* George C. Marshall Space Flight Center, Marshall Space Flight Center, AL, November 1977.

c.2.2 Conversion of Gust Gradient Time. Series, $\partial u_2/\partial x_1(t_n)$

In this example the same altitude and velocity are assumed for the Space Shuttle as in subsection C.2.1. This point in the trajectory, for simplicity, is assumed to correspond to the *first* term (N=1) in the dimensionless time series as recorded in the *third* record of SSTT-4 presented in Table C-2. The conversion steps proceed as follows:

1. Establish Proper Value for Index, i - Based on Table 2-1 for $\partial u_2/\partial x_1$ gust gradients, $i = 2$.
2. Establish Altitude Band - Based on Table 2-1 with $Z_1 = 9000$ m, the proper altitude band would be #4.
3. Read Dimensionless Time Increment, T_2 - Based on the *sixth* word (corresponding to Altitude Band #4) in the *second* record in SSTT-1, as presented in Table C-2, the dimensionless time increment, T_2, would be .05308717.
4. Determine Integral Scale, L_2 - Based on Table 3-3, with $Z_1 = 9000$ m, the proper integral scale, L_2, would be 533 meters.
5. Compute Dimensional Time -

$$t^*_{21} = \sum_{n=1}^{1} \Delta t^*_{2n}$$

$$= aT_2 \sum_{n=1}^{1} L_{2n}/V_n$$

$$= (1.339) \cdot (.05308717) \cdot (533/270)$$

$$= .1403 \text{ sec}$$

6. Read Dimensionless Gust Gradient - Based on the *fourth* word (corresponding to Altitude Band #4) in the *third* record (corresponding to N=1) the dimensionless gust gradient value is -4.476854.
7. Determine Standard Deviation in Direction of Gust - Based on Table 3-3 with $Z_1 = 9000$ m, the proper standard deviation, σ_2, would be 5.27 m/sec.